Fast switching liquid crystal compositions for use in bistable liquid crystal devices

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The invention is directed to the use of a fast switching liquid crystal composition in a bistable liquid crystal device and especially in a zenithal bistable nematic liquid crystal device, a nematic liquid crystal medium, and a bistable liquid crystal device comprising the fast switching liquid crystal composition.

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Electrooptical devices utilizing liquid crystal media for displaying information are well known and used in a wide variety of technical applications (see, for a review, H. Kawamoto, Proc. IEEE, 90, 460 (2002)). Among these, nematic liquid crystal devices are the most prominent; there are, for instance, twisted nematic (TN) liquid crystal devices (M. Schadt and W.

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Helfrich, Appl. Phys. Lett., 18, 127 (1971)) and super-twisted nematic (STN) liquid crystal devices (see, inter alia, T.J. Scheffer and J. Nehring, Appl. Phys. Lett., 48, 1021 (1984)). These devices are monostable, i.e. the liquid crystal medium is switched to an ON state by application of a suitable voltage, and is allowed to switch to an OFF state when the voltage applied

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falls below a lower voltage level. In order to display complex information electrooptical devices need to comprise a number of picture elements that can be switched independently of each other. However, when direct or even multiplex addressing of pixels are used, the number of elements addressable in nematic liquid crystal displays is limited, in the first case by

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mere geometrical requirements of the electrical connections and in the second case by the steepness of the device's transmission versus the voltage curve.

This limitation can be overcome by incorporating thin film transistors (TFT)
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into each picture element. Such devices, also known as active matrix (AM) displays, enable addressing of a high number of picture elements and thus

of large area high resolution displays and with relatively low voltage requirements. Some of these devices are also mechanically rather stable and have a wide temperature range. Although this allows the construction of small and portable battery powered displays, for certain applications the

5   techniques has several drawbacks. Manufacturing AM displays is still a complicated process involving the building up of a complex assembly which contributes to rather high costs of production. Since the device has no intrinsic or internal memory, constant update of the display even for static images is required. This causes relatively high power consumption and,

10   hence, rather poor battery life time. This is especially undesired with portable devices displaying information that is changed only from time to time or in a limited part of the display such as mobile phones, personal digital assistants (PDAs), pagers, electronic shelf edge labels, and the like.

15   An approach to avoid the limitations and drawbacks of these nematic liquid crystal devices is to use displays with an internal memory effect, e.g. a bistable liquid crystal device. Bistability means that the molecules of the liquid crystal medium inside the device can adopt two (or more) different stable states. Consequently, by applying a suitable addressing scheme the

20   liquid crystal molecules of the medium are switched into a first stable state which persists even after addressing; utilization of another addressing scheme causes the liquid crystal molecules to adopt a second stable state that likewise persists after addressing.

25   Ferroelectric liquid crystal displays using smectic liquid crystal materials can be made into bistable devices. They have, however, several disadvantages, e.g. lack of shock resistance, narrow operating temperature range, and low cell gap causing manufacturing difficulties. Therefore, these ferroelectric devices are unlikely to fulfill the requirements to displays for

30   the portable devices mentioned above.

However, not only ferroelectric smectic liquid crystals are capable of being used in bistable devices but also nematic liquid crystals. Besides other approaches that utilize bistable bulk configurations adopted by nematic liquid crystals (see, for instance, I. Dozov *et al.*, "Recent improvements of
5   bistable nematic displays switched by anchoring breaking (BiNem®)", Proceedings SID 01 (2001), 16.1, 224 and references therewithin), a promising way of achieving bistability in a nematic liquid crystal display is to use a surface alignment which can support two or more stable states. As discussed in literature (see, for instance, J.C. Jones, G. Bryan-Brown, E.
10   Wood, A. Graham, P. Brett and J. Hughes, "Novel bistable liquid crystal displays based on grating alignment", in "Liquid Crystal Materials, Devices, and Flat Panel Displays", R. Shashidhar, B. Gnade, Eds., Proceedings of SPIE Vol. 3955 (2000), 84 and references cited therein) two types, azimuthal and zenithal bistability, can be distinguished.

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In the first instance (i.e. azimuthal bistability), the director of the liquid crystal molecules in the display having a grating alignment on the surface of one of the display cell's plates (or substrates) will lie parallel to said plate in both stable states; that means that switching between the stable states
20   occurs within the plane of the display cell's plates (see, for instance, WO 92/00546 and WO 95/22077 which describes the use of a substrate having a bigrating alignment layer). However, reproducing selection of the stable states is found to be difficult and switching generally requires a high switching voltage.

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On the other hand, zenithal bistability is observed when the zenithal bistable surface is used (see Figure 1; the tiny lines represent the local director of the liquid crystal molecules that are oriented by interaction with the surface grating and appropriate alignment layer). With such a surface,
30   the director of the liquid crystal molecules has two possible configurations with different pretilt angles in the same azimuthal plane (i.e. the plane

perpendicular to the surface of the display cell's substrate). The first state is the high tilt state while the second state is the low tilt state. The grating of the zenithal bistable surface is defined by its amplitude a and its pitch L; typical values are for L of about 1 μm and for a of about 0.6 to 0.8 μm (see

5   WO 97/14990 and, for more details, WO 02/08825; and J.C. Jones, G. Bryan-Brown, E. Wood, A. Graham, P. Brett and J. Hughes, "Novel bistable liquid crystal displays based on grating alignment", in "Liquid Crystal Materials, Devices, and Flat Panel Displays", R. Shashidhar, B. Gnade, eds., Proceedings of SPIE Vol. 3955 (2000), 84).

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A homeotropic orientation can be, for example, induced by coating the grating with a homeotropic alignment layer; this orientation ensures that the director of the liquid crystal molecules does not lie parallel to the grooves of the grating. Although the orientation of the director of the liquid crystal

15   molecules is perpendicular to the (local) surface, i.e. varying with the location on the surface along a direction perpendicular to the grooves, the orientation in the "bulk" is very much influenced by the opposite surface alignment in both states. Switching from one stable state to the other may be achieved by applying a simple electrical pulse thereby causing a switch

20   from a black display or picture element to a white one (or vice versa) with the appropriate polariser configuration and retardation, and switching back to the original state occurs upon application of a pulse of opposite polarity thereby causing a switch from white to black (or vice versa). Switching may also be induced by using pulses of same polarity but with much higher

25   voltages (also referred to as "reverse switching"); however, reverse switching is a detrimental effect which limits the operation of a zenithal bistable nematic device in terms of the addressing and so a high a voltage as possible is desired for the reverse switching.

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In general, for obtaining zenithal bistability only one of the two display cell's substrates is provided with a surface grating. The opposite plate may have a surface providing a homeotropic alignment of the liquid crystal director (VAN mode, see Figure 2a)) or a surface inducing planar alignment of the director (twisted mode, see Figure 2b)) thereby causing the twisting of the liquid crystal director around the axis perpendicular to the substrates across the cell for the low tilt state. For details with regard to cell geometry and configuration, exact cell parameters, addressing means, assembling of the entire zenithal bistable device (including use of polarisers) and so on, see the disclosure of WO 97/14990, E.L. Wood, G.P. Bryan-Brown, P. Brett, A. Graham, J.C. Jones, and J.R. Hughes, "Zenithal Bistable Device (ZBD^{TM}) Suitable for Portable Applications, SID 00 Digest (2000), 124, J.C. Jones, J.R. Hughes, A. Graham, P. Brett, G.P. Bryan-Brown, and E.L. Wood, "Zenithal Bistable Devices: Towards the electronic book with a simple LCD", IDW '00 (2000), 301, J. C. Jones, S. M. Beldon and E .L. Wood, "Greyscale in Zenithal Bistable LCD: The Route to Ultra-low Power Colour Displays", seminar talk on the ASID meeting 2002 of the Society for Information Display, Singapore, September 2002; and the detailed discussion given in J.C. Jones, G. Bryan-Brown, E. Wood, A. Graham, P. Brett and J. Hughes, "Novel bistable liquid crystal displays based on grating alignment", in "Liquid Crystal Materials, Devices, and Flat Panel Displays", R. Shashidhar, B. Gnade, eds., Proceedings of SPIE Vol. 3955 (2000), 84, and references cited therein.

Utilizing zenithal bistability in electrooptical devices offers attractive features:

- Image retention on a display without continuous update combined with
- High mechanical shock stability
- Low power consumption since the display only needs addressing when the image changes

- Infinite multiplexibility for unlimited resolution without the need for TFT elements
- Transmissive and reflective modes possible
- Suitability for use with plastic substrates

Besides the assembly and make up of the zenithal bistable display, another key issue to the zenithal bistable device technology is the nematic liquid crystal medium used inside the display's cell.

The zenithal bistable device and hence the liquid crystal medium have to meet several requirements more or less depending on the specific use of the device. Since there is no consistent theory so far that might predict the physical variables to be optimized, it turned out to be helpful using a set of (semi-)empirical parameters for evaluating liquid crystal media with respect to their usefulness in zenithal bistable nematic devices. These are illustrated in the so-called τ-V curve for switching voltages of pulse duration τ and for 10 and 90% switching levels with opposite polarities (see figure 3) for a liquid crystal mixture of the prior art, namely MLC-6204-000 of Merck KGaA, Darmstadt, Germany.

Firstly, in order to minimize power consumption, to allow more flexibility with the addressing of the device's picture elements and to remain within the limits of standard STN drivers a low *switching field* and correspondingly a low *operating voltage* is desirable for switching from one bistable state to the other. For material comparison one can determine the switching field E for a pulse (usually a 100 µs pulse duration) from the switching voltage V that gives a transmission change from, e.g., 0 to 90% transmission (black-to-white; B-W) for a particular liquid crystal mixture in a given test cell providing zenithal bistability. (In general, one can also use the 100 to 10% transmission change transition of white-to-black, W-B, where the switching field of which may be higher or lower than the B-W transition depending on

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the grating's shape and dimensions.) In order to take into account the
voltage drop across the grating (which varies for different types of gratings
as well as cell thickness) the value of E actually measured is corrected to
distinguish the field just across the liquid crystal again for comparison

5   purposes giving the *corrected switching field* $E_{LC@100\mu s}$ for a 100 µs pulse.
Here, an additional factor of 1.5µm is added to the cell thickness d when
calculating the field just across the liquid crystal:

$$E_{100\mu s} = V_{100\mu s}/d \quad \text{and} \quad E_{LC@100\mu s} = V_{100\mu s}/(d+1.5) \quad \text{where d is in } \mu m.$$

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Multiplying $E_{LC@100\mu s}$ with *optimum cell gap* d_{opt} (that can be approximated
by using the TN 1st minimum condition $d_{opt} = \lambda\sqrt{3}/(2\Delta n)$ with λ = 555 nm
and Δn being the optical anisotropy of the liquid crystal medium) gives the
operating voltage V_{opt} corresponding to the optimum cell gap for a 100µs

15   pulse for just the liquid crystal. $E_{LC@100\mu s}$ and so V_{opt} depend on the liquid
crystal medium used. (The optimum cell gap is considered only for the
twisted mode (see Figure 2b)) here but comparisons can also be made for
the VAN mode (see Figure 2a)), where the retardation of the hybrid state
will be matched to either a half-wave plate of quarter-wave plate depending

20   on the polariser configuration ($d\Delta n=\lambda/2$ and $d\Delta n=\lambda/4$, respectively).

The second empirical parameter that needs to be taken into account is the
operating window ΔV_{opt} corresponding to the optimum cell gap. It describes
the effect of reverse switching: When applying a pulse with a given time

25   slot of, e.g. 400 µs, and a defined pulse polarity, e.g. B-W, one observes
the desired switching at a specific value of the switching field and a further
reverse switching (e.g. W-B in this case) which is not induced by a pulse of
inverse polarity but by a pulse of the same polarity at an increased
switching field. For technical purposes, obviously said operating window

30   ought to be as wide as possible to permit more flexibility of the driving
schemes used and particularly in relation to achieving good grayscale

operation (see J. C. Jones, S. M. Beldon and E. L. Wood, "Greyscale in
Zenithal Bistable LCD: The Route to Ultra-low Power Colour Displays",
seminar talk on the ASID meeting 2002 of the Society for Information
Display.) It can be represented by $\Delta E_{LC@400\mu s}$, that is the corrected

5   difference between the 90% reverse switching field and the 90% B-W
switching field for a 400 μs pulse:

$$\Delta E_{400\mu s} = \Delta V_{400\mu s}/d \text{ and } \Delta E_{LC@400\mu s} = \Delta V_{400\mu s}/(d+1.5) \text{ where d is in } \mu m.$$

10   Taking into account the optimum cell gap d_{opt} by multiplying with $\Delta E_{LC@400\mu s}$
eventually gives the operating window ΔV_{opt} ($d_{opt}\Delta E_{LC@400\mu s} = \Delta V_{opt}$).

Still another parameter of great importance is the *clearing point T_{NI}* of the
liquid crystal medium describing the temperature at which the nematic

15   mixture becomes isotropic. For many technical purposes and for increasing
the variability of electrooptical devices utilizing zenithal bistability (and so
the possible applications), liquid crystal media having a high clearing point,
preferably of at least 80 °C or more, are desired.

20   A further parameter, the *optical response time τ_{opt}* corresponding to the
optimum cell gap, describes how fast the liquid crystal medium changes
between stable states upon application of an electric pulse. It can be
determined by measuring the response time τ for the 10-90 % B-W
transition using a 100 μs pulse in the actual test cell; then, in order to

25   normalize the experimental values, τ is multiplied by $(d_{opt}/d)^2$ giving τ_{opt}
(with d_{opt} being the optimum cell gap as calculated above for V_{opt} and d
being the actual cell gap of the test cell used). The W-B transition is much
faster (less than 1ms) and so indeed the B-W response time is of most
importance when assessing the properties of the liquid crystal medium

30   used. The smaller τ_{opt} the faster the optical response of the liquid crystal
medium. A small τ_{opt} (of about 40 ms or, preferably, less than about 30 ms)

may be desirable for certain electrooptical applications, e.g. displaying moving pictures. It is even more preferred for specific video applications that τ_{opt} is less than about 16 ms so as not to observe flash.

5   Those liquid crystal media the use of which in zenithal bistable devices have been described in the prior art do not meet all the parameter requirements outlined above. Even liquid crystal mixture MLC-6204-000 (available from Merck KGaA, Darmstadt, Germany) that has been used in zenithal bistable devices as the preferred medium (WO 01/40853, Example

10   6; J.C. Jones, G. Bryan-Brown, E. Wood, A. Graham, P. Brett and J. Hughes, "Novel bistable liquid crystal displays based on grating alignment", in "Liquid Crystal Materials, Devices, and Flat Panel Displays", R. Shashidhar, B. Gnade, Eds., Proceedings of SPIE Vol. 3955 (2000), 84) has a clearing point T_{NI} of only 62.4 °C that is rather low for use in zenithal

15   nematic bistable device for many possible applications. Furthermore, its τ_{opt} is above 40 ms that is rather high for use in zenithal nematic bistable device for some specific applications requiring a small optical response time τ_{opt}.

20   The present invention therefore encounters the problem to provide a liquid crystal composition that is suitable for use in a bistable liquid crystal device and especially in a zenithal bistable nematic device and has an improved set of properties.

25   The problem is solved by the use of a liquid crystal composition in a bistable liquid crystal device, said device being preferably a zenithal nematic liquid crystal device, whereby said compostion comprises

- at least 30 weight% (based on the total weight of the composition) of a component (a) containing one or more compounds having a

30   dielectric anisotropy $\Delta\varepsilon$ of at least 25,

whereby at least 25 weight% (based on the total weight of the

composition) of said compounds have a dielectric anisotropy $\Delta\varepsilon$ of at least 40; and

- a component (δ) containing one or more compounds each having a ratio of γ_1/T_{NI}^K of 0.51 mPa·s/K or less, a clearing point T_{NI} of at least 100 °C and a rotational viscosity γ_1 of not more than 190 mPa·s (wherein γ_1 is the rotational viscosity at 20 °C in mPa·s and T_{NI}^K is the clearing point in degrees Kelvin).

(The dielectric anisotropy, the rotational viscosity and the clearing point can be determined according to the methods described in "Physical Properties of Liquid Crystals – Description of the measurement methods", ed. W. Becker, Merck KGaA, Darmstadt, 1998, whereby values for single compounds may be extrapolated from those determined using a known concentration (usually 10 weight% of the single compound) in a standard host mixture (usually ZLI-4792 of Merck KGaA, Darmstadt, Germany) for which the initial mixture values are also known. Further parameters of single compounds may be obtained similarily.)

A further subject matter of this invention is a bistable liquid crystal device comprising

- two outer substrates which, together with a frame, form a cell;
  - a liquid crystal composition present in said cell;
  - electrode structures with alignment layers on the inside of said outer substrates whereby at least one alignment layer comprises an alignment grating that permits the liquid crystal composition to adopt at least two different stable states whereby the assembly of said electrode structures with said alignment layers being such that a switching between the said at least two different stable states is achieved by applying suitable electric signals to said electrode structures;

* whereby said liquid crystal composition is said liquid crystal composition as described above and below and that comprises said components (*a*) and (*δ*).

5   In particular, said bistable liquid crystal device is a zenithal bistable nematic liquid crystal device in which said electrode structures with alignment layers on the inside of said outer substrates have at least one alignment layer that comprises an alignment grating that permits the compounds of said liquid crystal composition to adopt at least two different stable states with

10   different pretilt angles in the same azimuthal plane whereby the assembly of said electrode structures with said alignment layers being such that a switching between the said at least two different stable states is achieved by applying suitable electric signals to said electrode structures.

15   It will be acknowledged that the invention is described hereinafter primarily with regard to the use of the liquid crystal composition above in a zenithal bistable nematic liquid crystal device although it may be used in other liquid crystal devices as well, for instance, in bistable liquid crystal devices like azimuthal bistable liquid crystal devices as disclosed, inter alia, in WO

20   92/00546 and WO 95/22077. Thus, details are given for the zenithal bistable nematic liquid crystal device but can easily be adapted to the requirements of other types of bistable liquid crystal devices.

       The zenithal bistable nematic device and the liquid crystal composition for

25   use in a zenithal bistable nematic device according to the invention show an improved set of parameters said parameters being, inter alia, operating voltage, operating window, and, especially, clearing point. It should be noticed that, for instance, the clearing point of the liquid crystal compositions for use in the zenithal bistable nematic devices of the

30   invention is significantly higher than the clearing point of liquid crystal mixtures previously used in zenithal bistable nematic devices. Operating voltage and operating window are both in a range useful for operating of a

zenithal bistable nematic device. Furthermore, in the preferred embodiments of the invention the optical response time τ_{opt} is decreased significantly so that fast switching liquid crystal compositions for use in bistable liquid crystal devices and especially in zenithal bistable nematic

5   liquid crystal devices are obtained.

The cell that is part of the zenithal bistable nematic device according to the invention may be any conventional cell which allows the nematic liquid crystal composition to adopt at least two different zenithal bistable states.

10   Two possible stable states are schematically depicted in Figure 1. The two different zenithal bistable states are characterized by two different pretilt angles that are adopted by the liquid crystal molecules in the same azimuthal plane. The cell comprises a frame and two outer substrates or plates and has electrode structures with alignment layers on the inside of

15   said substrates. At least one of these alignment layers has an zenithal alignment grating known to those skilled in the art and as described, for instance, in WO 97/14990, WO 01/40853, WO 02/08825, and J.C. Jones, et al., Proceedings of SPIE Vol. 3955 (2000), 84.

20   The electrode structures are assembled with the alignment layer(s) in such a way that (in the case of two stable states) switching from one stable state to the other can be achieved by applying suitable electric signals to the electrode structures thereby applying said electric signals to the liquid crystal composition inside the cell. Commonly, single pulses can be used

25   as such suitable electric signals. Details are known to the artisan and described in WO 97/14990, WO 01/40853, WO 02/08825, J.C. Jones, J.R. Hughes, A. Graham, P. Brett, G.P. Bryan-Brown, IDW '00 (2000), 301, J.C. Jones, et al., Proceedings of SPIE Vol. 3955 (2000), 84, and E. L. Wood, P. J. Brett, G. P. Bryan-Brown, A. Graham, R. M. Amos, S. Beldon, E.

30   Cubero and J. C. Jones, "Large Area, High Resolution Portable ZBD Display", SID 02 Digest (2002), 22-25.

The substrate opposite to the substrate having the grating alignment layer may have an homeotropic alignment due to suitable surface treatment (see Figure 2a)). Switching upon application of an electric pulse occurs from the high tilt or vertically aligned state to the low tilt or hybrid aligned state. This switch gives a black-to-white (B-W) change if the cell is placed between crossed polarizers (at 45° to the grating direction), with the brightest white state obtained when the vertically aligned state acts as a half-waveplate ($d\Delta n=\lambda/2$). This switching mode is called *VAN mode*. Zenithal bistable devices utilizing the VAN mode are very insensitive to cell gap variations. They require additional optical compensators to achieve wide viewing angles. A second switching mode of zenithal bistable devices is called *TN mode* (see Figure 2b)): The substrate opposite to the substrate having the grating alignment layer has a alignment layer, usually of rubbed polyimide, causing planar alignment of the liquid crystal molecules on said substrate. This in turn causes the twisting of the liquid crystal director around their axis perpendicular to the substrates across the cell. Switching upon application of an electric pulse now occurs from the low tilt or twisted aligned state to the high tilt or hybrid aligned state. This switch gives a black-to-white (B-W) change if the cell is placed between parallel polarizers and using the slightly modified TN 1st minimum condition (as given above) accounting for the influence of the ordinary refractive index of the hybrid state. Due to a high normal incidence contrast ratio additional optical compensators for achieving wide viewing angles are not required in a transmissive display. Therefore the TN mode is preferred for most of the technical applications of zenithal bistable nematic devices. It is also possible to build up a zenithal bistable reflective display and even a zenithal bistable transflective display. For details, also with regard to the polarizers used, it is referred to WO 97/14990, E.L. Wood, G.P. Bryan-Brown, P. Brett, A. Graham, J.C. Jones, and J.R. Hughes, SID 00 (2000), 124, and E. L. Wood, P. J. Brett, G. P. Bryan-Brown, A. Graham, R. M.

Amos, S. Beldon, E. Cubero and J. C. Jones, "Large Area, High Resolution Portable ZBD Display" SID 02 Digest (2002), 22-25.

In the context of the present invention and with respect to the compounds
5   contained in the liquid crystal composition for use in bistable liquid crystal devices and especially in zenithal bistable nematic devices of the invention the term "alkyl" means - as long as it is not defined in a different manner elsewhere in this description or the claims - straight-chain and branched hydrocarbon (aliphatic) radicals with 1 to 15 carbon atoms; the hydrocarbon
10   radicals may be unsubstituted or substituted with one or more substituents being independently selected from the group consisting of F, Cl, Br, I or CN. This subclass of "alkyl" containing aliphatic saturated radicals may also be designated as "alkanyl". Furthermore, "alkyl" is also meant to comprise unsubstituted or likewise substituted hydrocarbon radicals in which one or
15   more of the CH_2 groups are such replaced by -O- ("alkoxy", "oxaalkyl"), -S- ("thioalkyl"), -CH=CH- ("alkenyl"), -C≡C- ("alkinyl"), -CO-O- or -O-CO- that there are no adjacent hetero atoms (O, S). Preferably, alkyl is a straight-chain or branched saturated hydrocarbon having 1, 2, 3, 4, 5, 6, 7 or 8 carbon atoms and being unsubstituted or mono- or poly-substituted with F.
20   More preferably, alkyl is meant to be methyl, ethyl, n-propyl, i-propyl, n-butyl, i-butyl, t-butyl, n-pentyl, neopentyl, n-hexyl, n-heptyl, n-octyl; CF_3, CHF_2, CH_2F; CF_2CF_3. Most preferably, alkyl is a straight-chain hydrocarbon of up to 8 carbon atoms.

25   Since one or more CH_2 groups of an alkyl radical may be replaced by -O- as described above, the term "alkyl" also comprises "alkoxy" and "oxaalkyl" moieties. "Alkoxy" means "O-alkyl" in which the oxygen atom is directly linked to the group or ring being substituted with alkoxy and alkyl is defined as above. In particular, "alkyl" in "O-alkyl" means methyl, ethyl, n-propyl, i-
30   propyl, n-butyl, i-butyl, t-butyl, n-pentyl, neopentyl, n-hexyl, n-heptyl or n-octyl, whereby alkyl is optionally substituted with F. Most preferably, alkoxy

is $-OCH_3$, $-OC_2H_5$, $-O-n-C_3H_7$, $-O-n-C_4H_9$, $-O-t-C_4H_9$, $-OCF_3$, $-OCHF_2$,
$-OCHF$ or $-OCHFCHF_2$. In the context of the present invention the term
"oxaalkyl" comprises alkyl moieties in which at least one non-terminal CH_2
group is replaced by O in such a way that there are no adjacent oxygen

5   atoms. Preferably, oxaalkyl comprises straight-chain radicals of the formula
$C_tH_{2t+1}-O-(CH_2)_u-$ in which t and u are independently of each other 1, 2, 3,
4, 5 or 6; especially t is 1 or 2 and u is an integer from 1 to 6.

If one or more of the CH_2 groups of alkyl are replaced by sulfur a "thioalkyl"

10   radical is obtained. Thioalkyl comprises alkyl moieties in which at least one
terminal or non-terminal CH_2 group is replaced by S (sulfur) in such a way
that there are no adjacent sulfur atoms. Preferably, thioalkyl comprises
straight-chain radicals of the formula $C_tH_{2t+1}-S-(CH_2)_u-$ in which t is 1, 2, 3,
4, 5 or 6 and u is 0, 1, 2, 3, 4, 5 or 6; especially t is 1 or 2 and u is zero or

15   an integer from 1 to 6.

In the context of the present invention the term "alkenyl" means an alkyl
radical in which one or more $-CH=CH-$ moieties are present. When two
$-CH=CH-$ moieties are present the radical may also be designated as

20   "alkadienyl". An alkenyl radical may comprise 2 to 15 carbon atoms and
may be straight-chain or branched. It can be unsubstituted or mono- or
polysubstituted with F, Cl, Br, I or CN; one or more of its CH_2 groups may
be replaced independently of each other by -O-, -S-, $-C\equiv C-$, -CO-O-,
-OC-O- such that there are no hetero atoms adjacent to each other. If the

25   alkenyl CH=CH moiety is not a terminal CH_2=CH group it may exist in two
configurations, namely the E-isomer and the Z-isomer. In general, the E-
isomer (trans) is preferred. Preferably, alkenyl contains 2, 3, 4, 5, 6 or 7
carbon atoms and means vinyl, 1E-propenyl, 1E-butenyl, 1E-pentenyl, 1E-
hexenyl, 1E-heptenyl, 2-propenyl, 2E-butenyl, 2E-pentenyl, 2E-hexenyl,

30   2E-heptenyl, 3-butenyl, 3E-pentenyl, 3E-hexenyl, 3E-heptenyl, 4-pentenyl,

4Z-hexenyl, 4E-hexenyl, 4Z-heptenyl, 5-hexenyl and 6-heptenyl. More preferred alkenyl is vinyl, 1E-propenyl, 3E-butenyl.

In the case one or more CH_2 alkyl groups are replaced by -C≡C- an alkinyl radical is obtained. Also the replacement of one or more CH_2 alkyl groups by -CO-O- or -O-CO- is possible. The following of these radicals are preferred: acetyloxy, propionyloxy, butyryloxy, pentanoyloxy, hexanoyloxy, acetyloxymethyl, propionyloxymethyl, butyryloxymethyl, pentanoyloxymethyl, 2-acetyloxyethyl, 2-propionyloxyethyl, 2-butyryloxyethyl, 2-acetyloxypropyl, 3-propionyloxypropyl, 4-acetyloxybutyl, methoxycarbonyl, ethoxycarbonyl, propoxycarbonyl, butoxycarbonyl, pentoxycarbonyl, methoxycarbonylmethyl, ethoxycarbonylmethyl, propoxycarbonylmethyl, butoxycarbonylmethyl, 2-(methoxycarbonyl)ethyl, 2-(ethoxycarbonyl)ethyl, 2-(propoxycarbonyl)-ethyl, 3-(methoxycarbonyl)-propyl, 3-(ethoxy-carbonyl)-propyl oder 4-(methoxycarbonyl)-butyl.

The liquid crystal composition for use in the (zenithal) bistable (nematic) liquid crystal device of the invention contains at least two different components, component (a) and component (δ).

It has been found by the inventors that the liquid crystal composition for use in a bistable liquid crystal device needs to comprise a component (δ) which may influence the optical response time τ_{opt} as desired. This component (δ) contains one or more compounds each having a ratio of $\gamma_1/T_{NI}{}^K$ ≤0.51 mPa·s/K, a clearing point T_{NI} ≥100 °C and a rotational viscosity γ_1 ≤190 (wherein γ_1 is the rotational viscosity at 20 °C in mPa·s and $T_{NI}{}^K$ is the clearing point in degrees Kelvin).

It is preferred that component (δ) contains at least one compound having a ratio of $\gamma_1/T_{NI}{}^K$ of 0.46 mPa·s/K or less, a clearing point T_{NI} of at least 110 °C and a rotational viscosity γ_1 of not more than 180 mPa·s. It is even more

preferred that the ratio of γ_1/T_{NI}^K is 0.42 mPa·s/K or less, the clearing point T_{NI} is of at least 120 °C and the rotational viscosity γ_1 of said compound is of not more than 175 mPa·s.

Component (δ) may be present in an amount of about 5 weight% (based on the total weight of the composition) but usually not more than about 65 weight%. It is preferred that its amount is in the range from about 7 to about 50 weight%, more preferred in the range from about 10 to about 35 weight%.

It is further preferred that said component (δ) comprises at least one compound of formula I

                                                                                              I

in which

R^{11} and R^{12} are independently of each other C_1-C_{15} alkyl which is
                    unsubstituted or mono- or poly-substituted with CN or halogen
                    and in which one or more of the CH_2 groups may be replaced
                    independently of each other by -O-, -S-, -CH=CH-, -C≡C-,
                    -CO-O-, -OC-O- such that there are no hetero atoms adjacent
                    to each other;
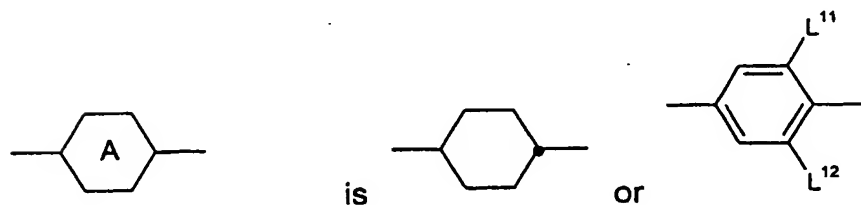
in which

L^{11} and L^{12} are independently of each other H or F; and
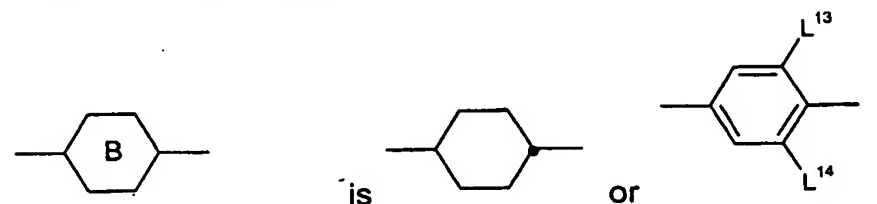
in which

L^{13} and L^{14} are independently of each other H or F.

Preferred compounds of formula I are compounds of one of the formulas I-A to I-I

C_mH_{2m-1} —⟨ ⟩—⟨ ⟩—⟨ ⟩— C_nH_{2n+1} I-A

C_pH_{2p-3} —⟨ ⟩—⟨ ⟩—⟨ ⟩— C_nH_{2n+1} I-B

C_mH_{2m-1} —⟨ ⟩—⟨ ⟩—⟨ ⟩— C_nH_{2n+1} I-C

C_qH_{2q+1} —⟨ ⟩—⟨ ⟩—⟨ ⟩— C_nH_{2n+1} I-D

C_qH_{2q+1} —⟨ ⟩—⟨ ⟩—⟨ ⟩— C_nH_{2n+1} I-E

C_qH_{2q+1} —⟨ ⟩—⟨ ⟩—⟨ ⟩— C_nH_{2n+1} I-F

C_mH_{2m-1} —⟨ ⟩—⟨ ⟩—⟨ ⟩— C_rH_{2r-1} I-G

C_qH_{2q+1} —⟨ ⟩—⟨ ⟩—⟨ ⟩— C_nH_{2n+1} I-H

C_mH_{2m-1} —⟨ ⟩—⟨ ⟩—⟨ ⟩— C_rH_{2r-1} I-I
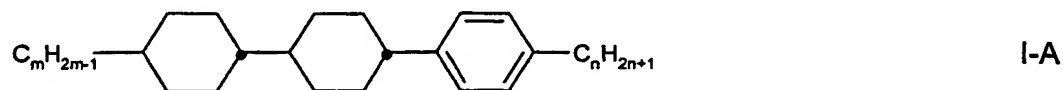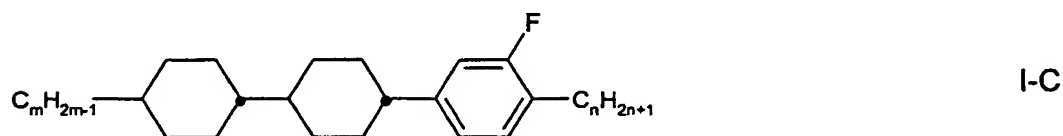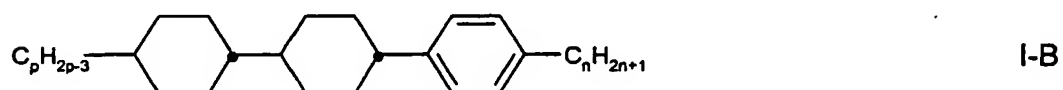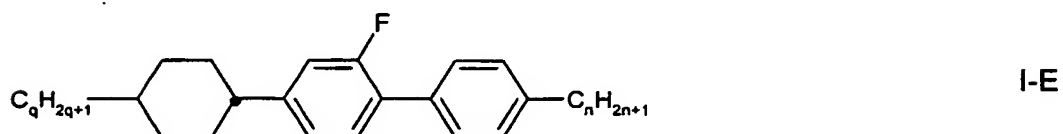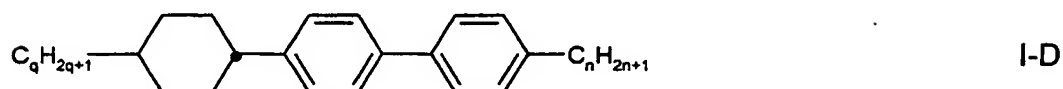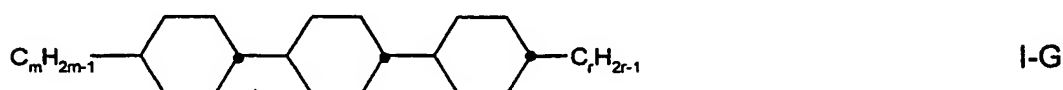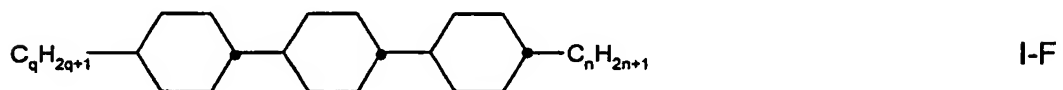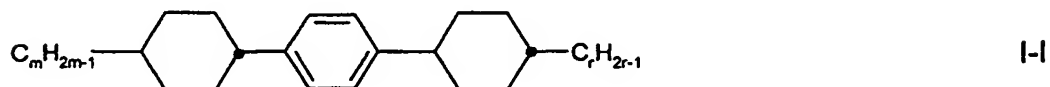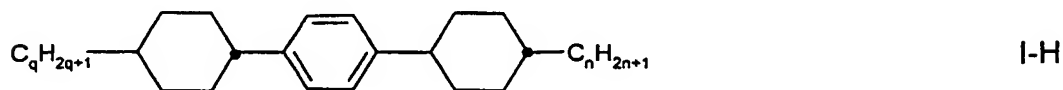
wherein m and r are independently of each other 2, 3, 4, 5, 6 or 7, n and q are independently of each other 1, 2, 3, 4, 5, 6 or 7, and p is 4, 5, 6, 7 or 8.

More preferred are compounds of formulas I-A and I-B, i.e. compounds of formula I in which R^{11} is alkenyl with up to 7 carbon atoms or alkadienyl with up to 8 carbon atoms, R^{12} is alkanyl with up to 7 carbon atoms, the ring indicated by A is a cyclohexyl ring, and the ring indicated by B is a phenyl ring. Also, compounds of formulas I-D, I-E, I-G, I-H and I-I are likewise preferred. Especially preferred are compounds of formula I-A with m being 2, 3, 4 or 5 and n being 1, 2, 3 or 4.

Specific examples of compounds according to formula I are the following:

I1

I2

I3

I4

I5

I6

I7

I8

I9

I10

I11

I12

I13
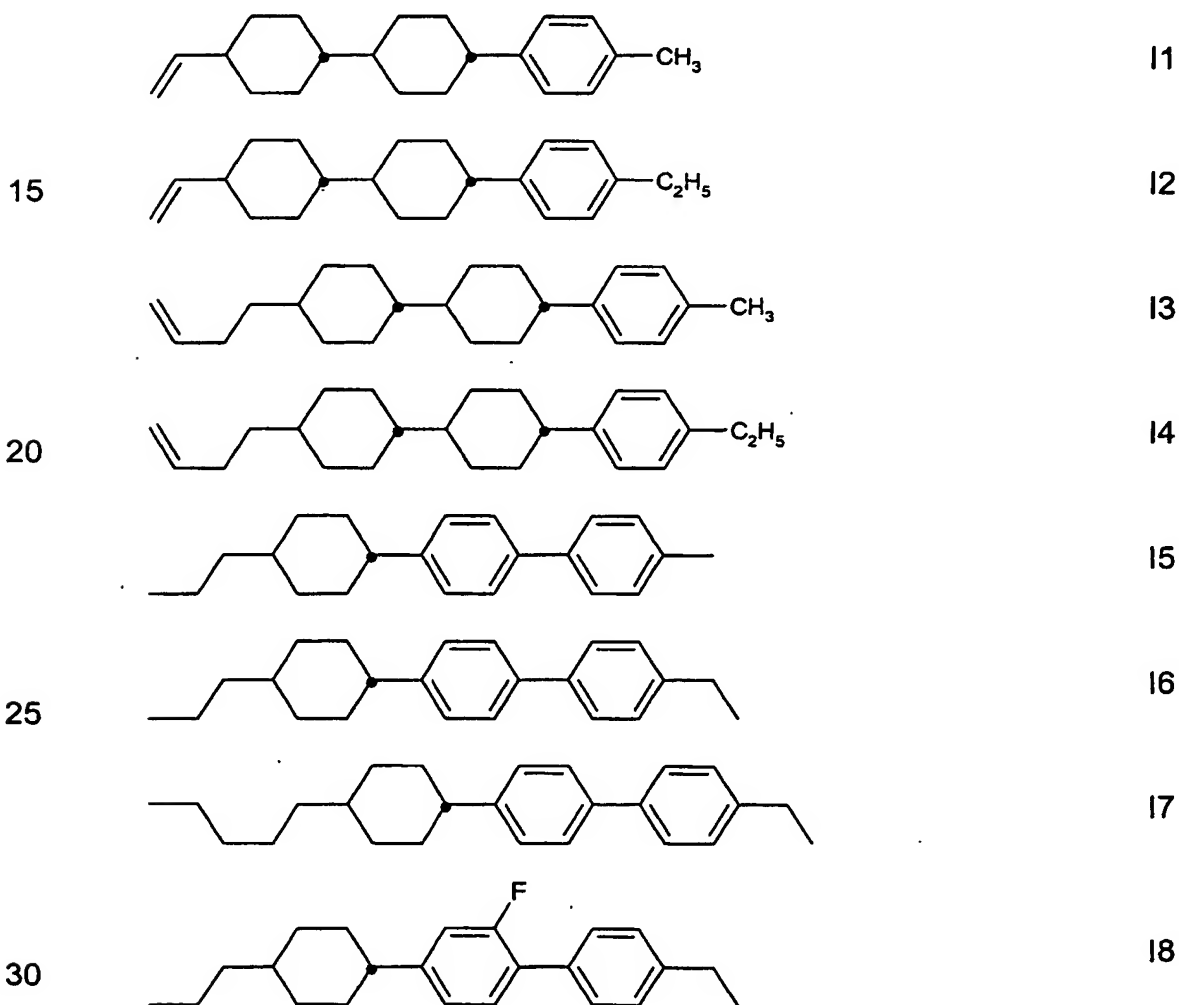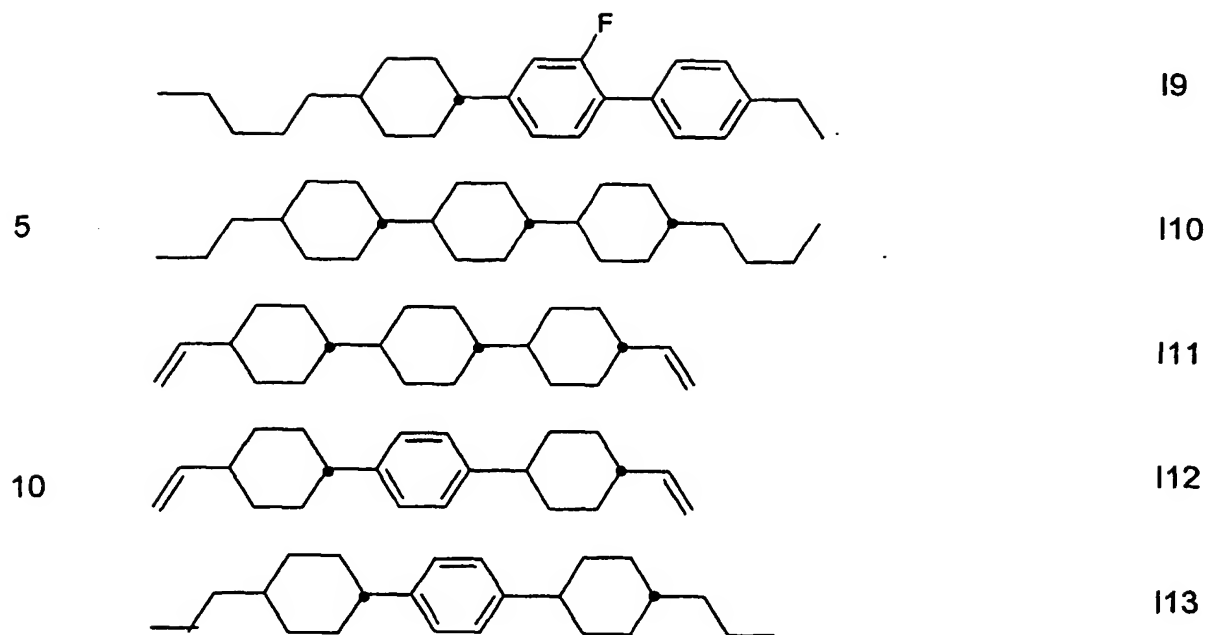
with I1 and I3 being the most preferred ones.

The following table, Table 1, shows the values of γ_1 (in mPa·s), T_{NI} (in degrees Celsius, °C) and γ_1/T_{NI}^K (in mPa·s/K) for some specific examples of compound I that is preferably comprised by component (δ).

Table 1

Compound	γ_1 / mPa·s	T_{NI} / °C	γ_1/T_{NI}^K / mPa·s/K
I1	118	161	0.27
I3	159	181	0.35
I5	118	192	0.25
I6	100	175	0.22
I7	149	190	0.32
I8	154	124	0.39
I9	174	138	0.42
I10	157	265	0.29
I11	94	220	0.19
I12	88	116	0.23
I13	111	154	0.26

The other component required according to the invention, component (*a*), contains one or preferably more compounds having a high dielectric anisotropy $\Delta\varepsilon$ of 25 or more, especially of 30 or more. At least 25 weight%, preferably 30 weight% or more, (based on the total weight of the

5 composition) of the compounds of component (*a*) exhibit a dielectric anisotropy $\Delta\varepsilon$ of 40 or more. At least 30 weight% (based on the whole composition) of component (*a*) need to be comprised by the liquid crystal composition of the zenithal bistable nematic device according to the invention. It is preferred that the liquid crystal composition comprises 35

10 weight% or more, even more preferred at least 40 weight%, still more preferred at least 45 weight%, most preferred 50 weight% or more, of said component (*a*).

It is preferred that said component (*a*) comprises at least one compound of

15 formula II and/or at least one compound of formula III

20
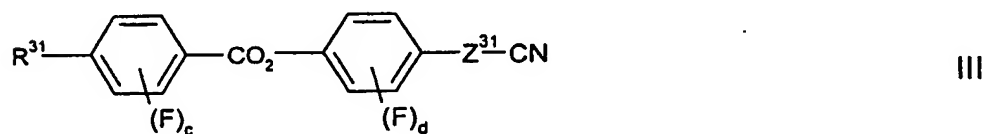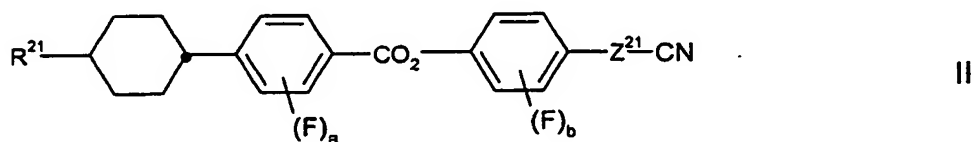
in which

25 a, b, c and d   are independently of each other 0, 1, 2, 3 or 4;

R²¹   is C_1-C_{15} alkyl which is unsubstituted or mono- or poly-
                 substituted with CN or halogen and in which one or more of
                 the CH_2 groups may be replaced independently of each other
                 by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that there

30   are no hetero atoms adjacent to each other;

- 22 -

R^{31} is C_2-C_{15} alkenyl which is unsubstituted or mono- or poly-
                  substituted with CN or halogen and in which one or more of
                  the CH_2 groups may be replaced independently of each other
                  by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that there
5   are no hetero atoms adjacent to each other;

Z^{21} and Z^{31} are independently of each other a single bond or -C≡C-.

It has been found by the inventors that component (a) preferably comprises
either one or more compounds of formula II or one or more compounds of
10   formula III or one or more compounds of both formula II and formula III
(besides other compounds having the required high dielectric anisotropy
that may be present). In one preferred embodiment of the invention
component (a) contains at least one compound of formula II but no
compound of formula III; in another preferred embodiment component (a)
15   contains at least one compound of formula III but no compound of formula
II. If component (a) contains at least one compound of formula II, said
compound(s) of formula I may be present in a total amount of at least 5
weight%, preferably at least 10 weight%, more preferred at least 15
weight% or more. If component (a) contains one compound of formula III,
20   said compound of formula II may be present in an amount of about 5 to 30
weight%, preferably 8 to 25 weight%, more preferred 10 to 20 weight%.
However, if component (a) contains more than one compound of formula
III, the total amount of these compounds is in the range of about 5 to about
55 weight%, preferably about 8 to about 35 weight%, more preferred about
25   9 to about 25 weight%.

With regard to compounds of formula II a and b may be independently of
each other 0, 1, 2, 3 or 4, preferably 0, 1 or 2; that means that preferably
each of the phenyl rings of formula II may be unsubstituted or mono- or di-
30   substituted with fluorine. If present the F substituent(s) may be in any

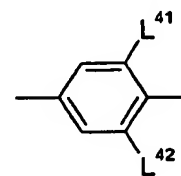position of the phenyl ring substituted. It is preferred that
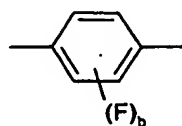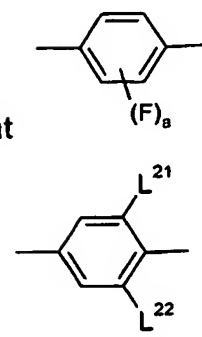
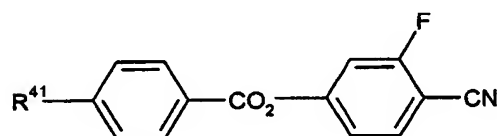and/or $(F)_b$ are independently of one another with

L^{21} and L^{22} being independently of one another H or F. Furthermore, Z^{21} can be either a single bond (so that the CN group is directly linked to the phenyl ring) or a C-C triple bond thereby forming a $-C{\equiv}C-CN$ substituent of the phenyl ring. It is preferred that Z^{21} is a single bond.
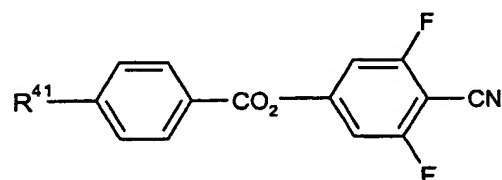
Preferred compounds of formula II are the following compounds:

II-A

II-B

II-C

II-D

II-E

5

II-F

II-G

10

II-H

15

II-J

20

II-K

II-L

25

II-M
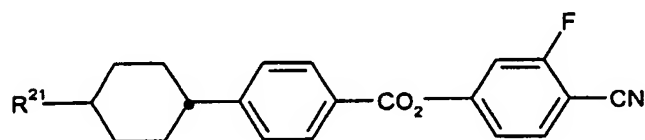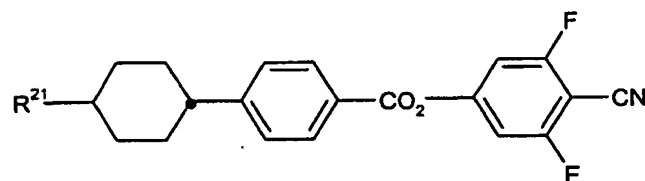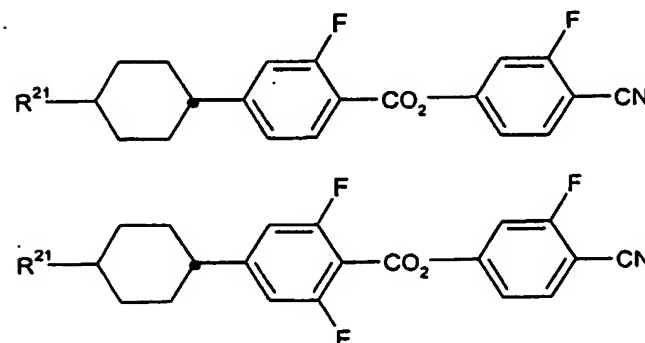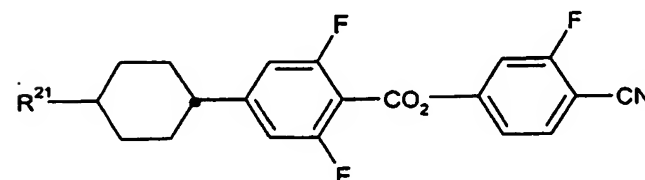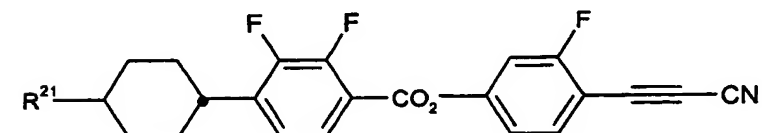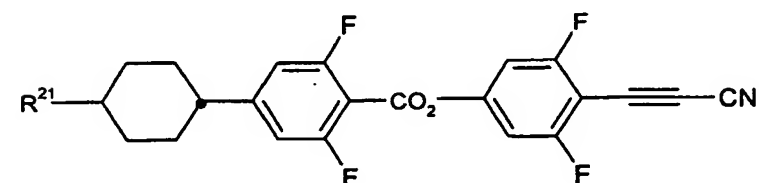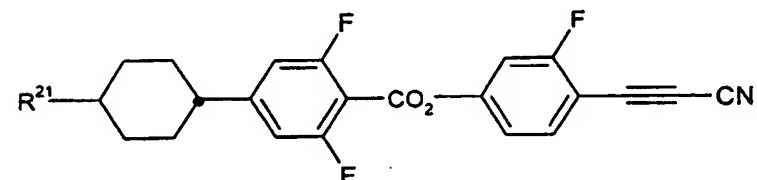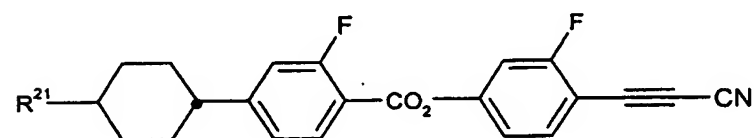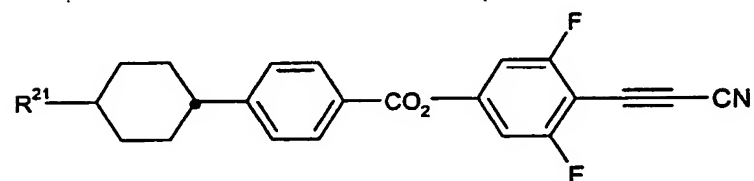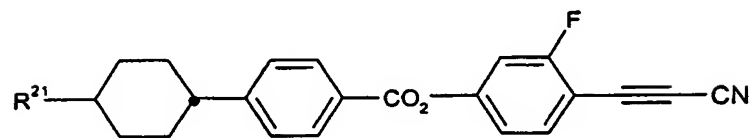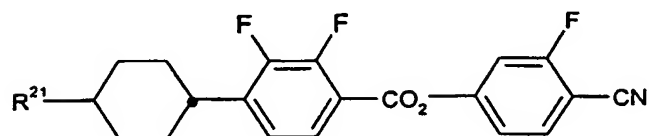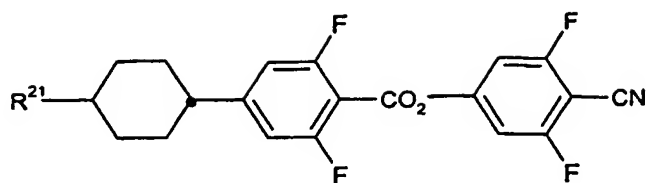
30   with R^{21} being defined as above. Preferably, R^{21} in formulas II and II-A to II-M is a straight-chain alkyl radical, especially an alkanyl radical with 1, 2, 3,

4, 5 or 6 carbon atoms. Highly preferred compounds are of general formula II-A1 with n = 1, 2, 3, 4, 5 or 6.

5

II-A1
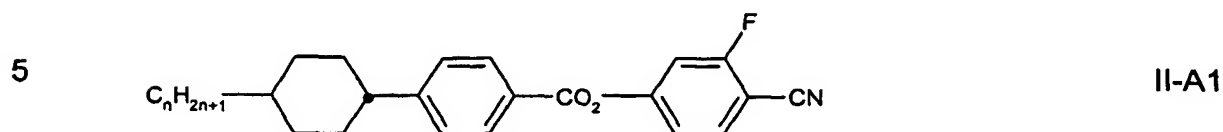
Especially preferred examples of compounds of formula II being present in component (*a*) either alone or in combination with each other are the

10 following compounds of formula II1 to II3:

II1

15

II2

II3

20
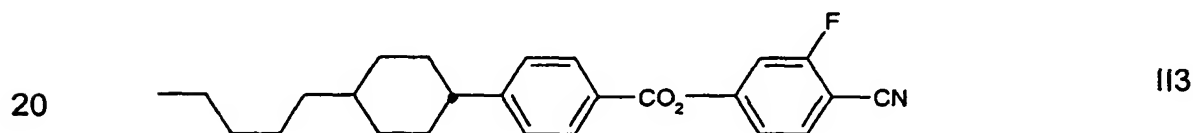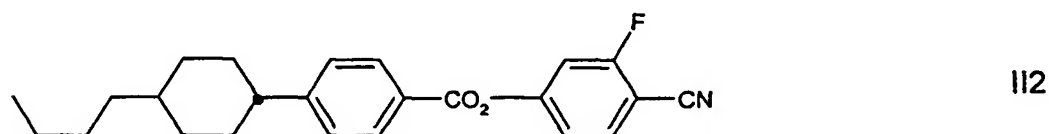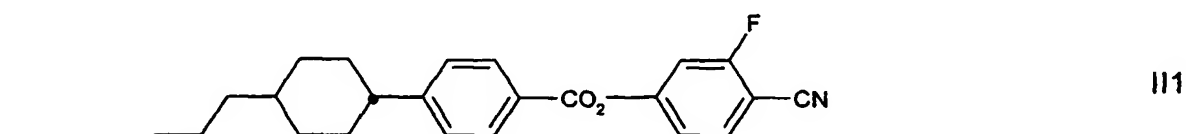
It is preferred to have a mixture of all three compounds II1, II2 and II3 in the liquid crystal composition. For instance, compound II1 exhibits a dielectric anisotropy $\Delta\varepsilon$ of 37.5 whereas compound II3 has a $\Delta\varepsilon$ of 36.0.

25

With regard to compounds of formula III c and d may be independently of each other 0, 1, 2, 3 or 4, preferably 0, 1 or 2; that means that preferably each of the phenyl rings of formula III may be unsubstituted or mono- or di-substituted with fluorine. If present the F substituent(s) may be in any

30

position of the phenyl ring substituted. It is preferred that

and/or $(F)_d$ are independently of one another L^{31} L^{32} with L^{31} and L^{32} being independently of one another H or F. Furthermore, Z^{31} can be either a single bond (so that the CN group is directly linked to the phenyl ring) or a C-C triple bond thereby forming a $-C{\equiv}C-CN$ substituent of the phenyl ring. It is preferred that Z^{31} is a single bond.

Preferred compounds of formula III are the following compounds:

III-A

R^{31}—⬡—CO_2—⬡—CN (with F substituent)

III-B

R^{31}—⬡—CO_2—⬡—CN (with F, F substituents)

III-C

R^{31}—⬡—CO_2—⬡—CN (with F, F substituents)

III-D

R^{31}—⬡—CO_2—⬡—CN (with F, F, F substituents)

III-E

5

III-F

10

III-G

III-H

15

III-J

20

III-K

III-L

25
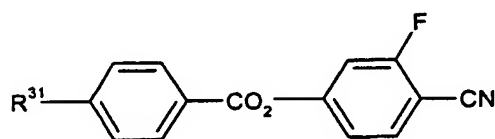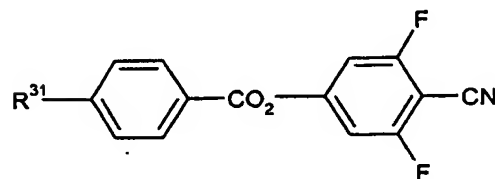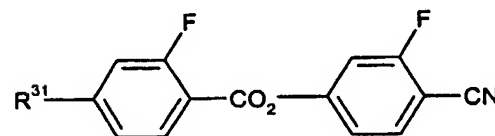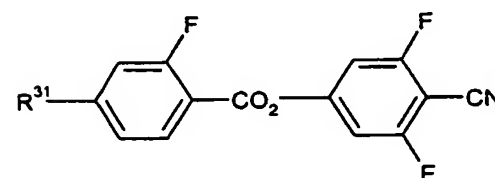
III-M

30
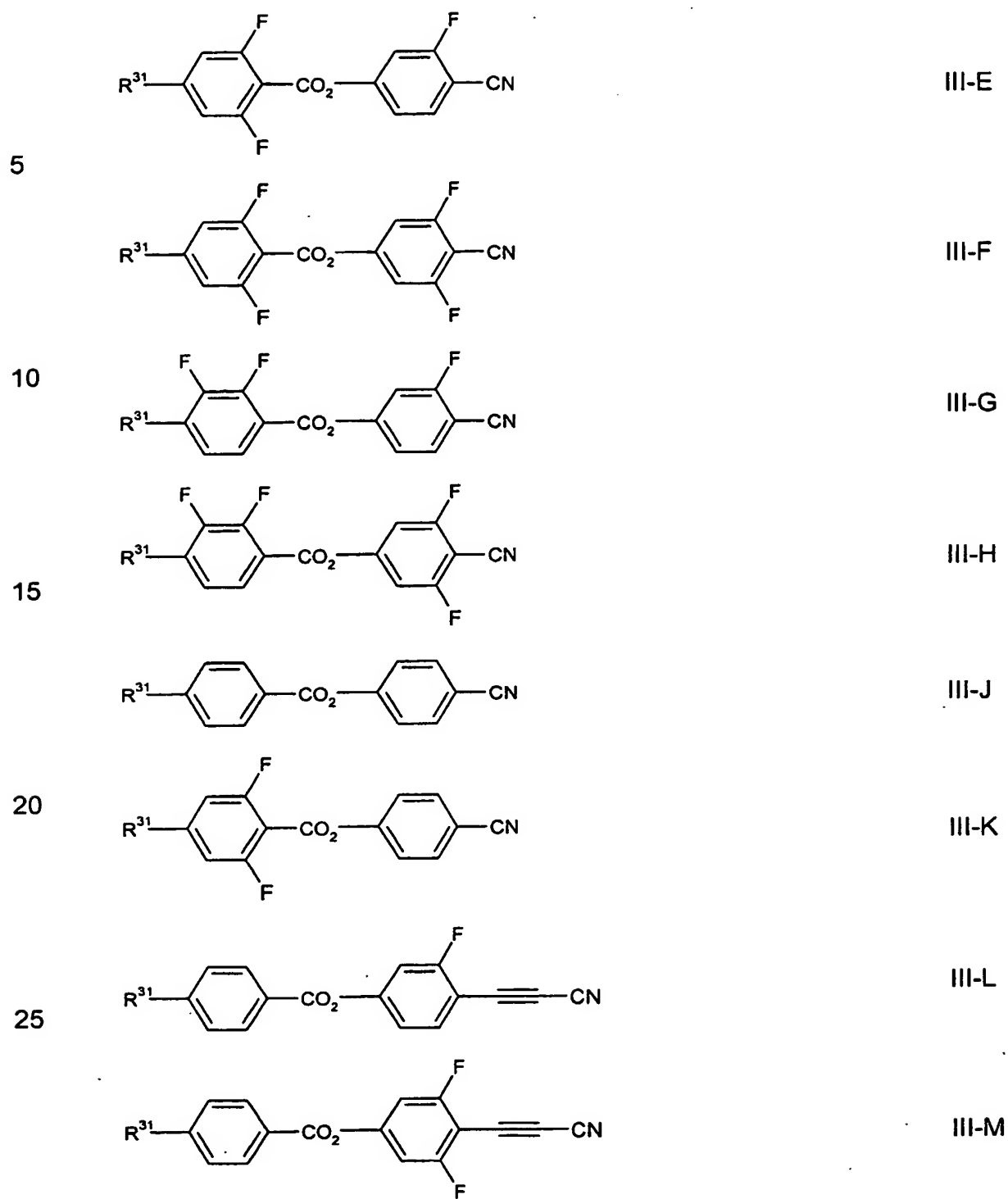
with R^{31} being defined as above. Preferably, R^{31} in formulas III and III-A to III-M is a straight-chain alkenyl radical, especially with 1, 2, 3, 4, 5 or 6 carbon atoms and most preferred with a terminal C=C double bond. Highly preferred compounds are of general formula III-B1 with n = 2, 3, 4, 5 or 6.

5
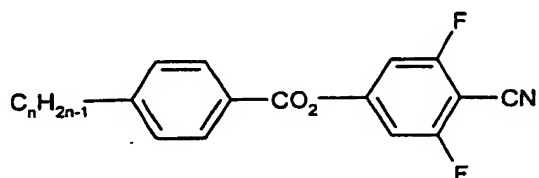
III-B1

10

Especially preferred examples of compounds of formula III being present in component (*a*) either alone or in combination with each other are the following compounds of formula III1 to III4:

15

III1

20

III2

III3

25

III4

30
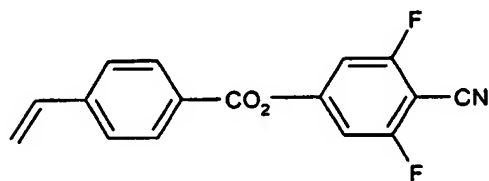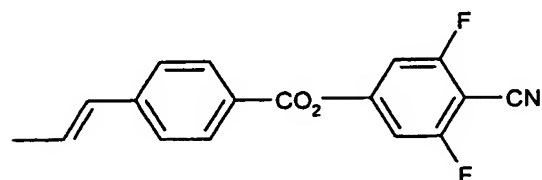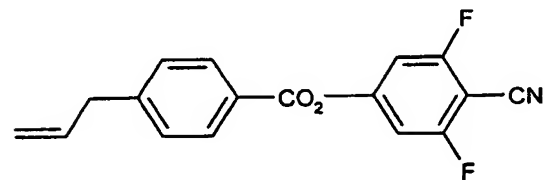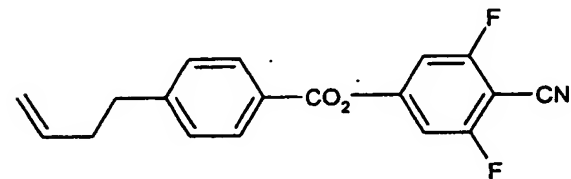
The most preferred compound of formula III is compound III4 which exhibits a dielectric anisotropy $\Delta\varepsilon$ of 59.5.

5   It will be acknowledged that other compounds than those of formulas II and III may be present in component (a) as long as they have a sufficiently high dielectrical anisotropy $\Delta\varepsilon$ and are not detrimental to the set of parameters as outlined above.

10   Thus, it is preferred that component (a) of the liquid crystal composition used in the zenithal bistable nematic device of the invention also comprises one or especially more compounds of formula IV

                                                                                    IV

15
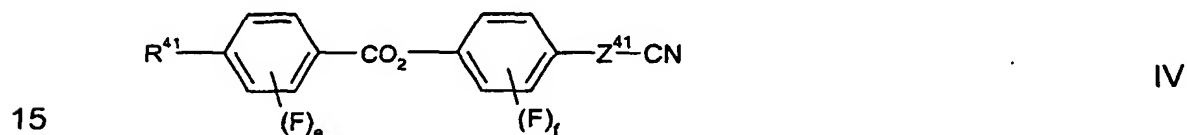
in which

e and f   are independently of each other 0, 1, 2, 3 or 4;

R^{41} is C_1-C_{15} alkyl which is unsubstituted or mono- or poly-

20   substituted with CN or halogen and in which one or more of
             the CH_2 groups may be replaced independently of each other
             by -O-, -S-, -C≡C-, -CO-O-, -OC-O- such that there are no
             hetero atoms adjacent to each other (which means that R^{41}
             does not comprise any alkenyl radical);

25   Z^{41} is a single bond or -C≡C-.

30

With regard to compounds of formula IV e and f may be independently of each other 0, 1, 2, 3 or 4, preferably 0, 1 or 2; that means that preferably each of the phenyl rings of formula IV may be unsubstituted or mono- or di-substituted with fluorine. If present the F substituent(s) may be in any

5

position of the phenyl ring substituted. It is preferred that $(F)_e$

10
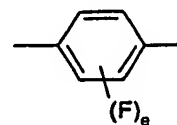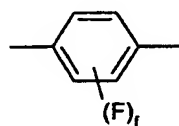
and/or $(F)_f$ are independently of one another L^{41} L^{42} with L^{41} and L^{42} being independently of one another H or F. Furthermore, Z^{41} can be either a single bond (so that the CN group is directly linked to the phenyl ring) or a C-C triple bond thereby forming a $-C \equiv C-CN$ substituent of

15   the phenyl ring. It is preferred that Z^{41} is a single bond.

Preferred compounds of formula IV are the following compounds:

20   R^{41}—⬡—CO_2—⬡—CN (F)   IV-A

        R^{41}—⬡—CO_2—⬡—CN (F, F)   IV-B

25

        R^{41}—⬡—CO_2—⬡—CN (F, F)   IV-C

30

IV-D

5

IV-E

10

IV-F

15

IV-G

IV-H

20

IV-J

IV-K

25

IV-L

30

IV-M
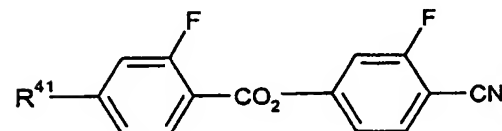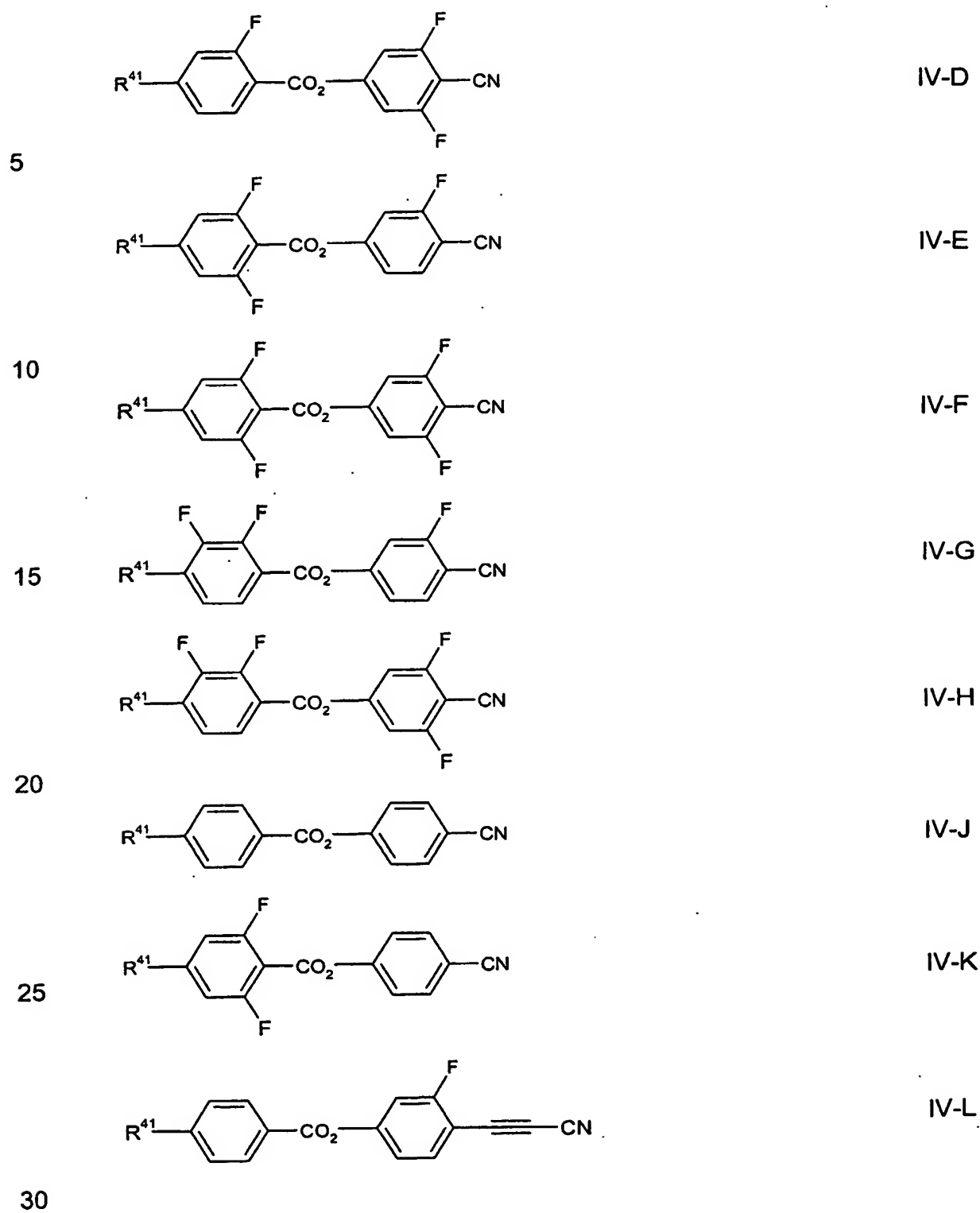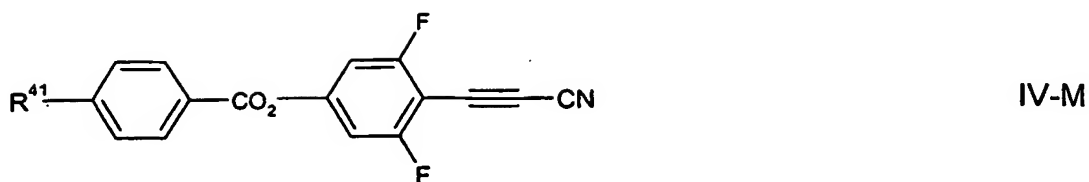
5

with R^{41} being defined as above. Preferably, R^{41} in formulas IV and IVA to IV-M is straight-chain alkyl, especially straight-chain alkanyl having 1, 2, 3, 4, 5, 6, 7 or 8 carbon atoms. Highly preferred compounds are of general formulas IV-A1 and IV-B1 with n = 1, 2, 3, 4, 5 or 6, whereby compounds of formula IV-A1 are most preferred.

IV-A1

IV-B1
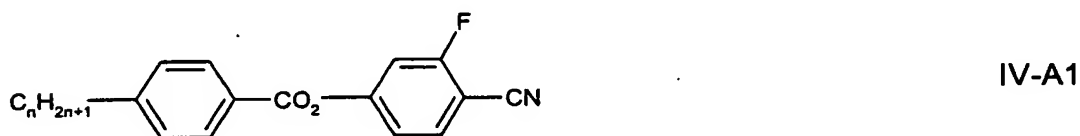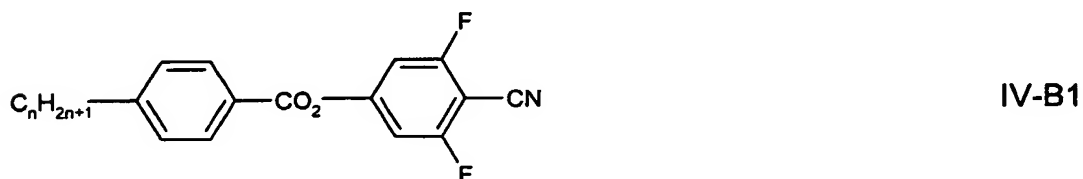
Especially preferred compounds of formula IV are compounds of formula IV1 to IV6:

IV1

IV2

IV3

IV4

5

IV5

IV6

10
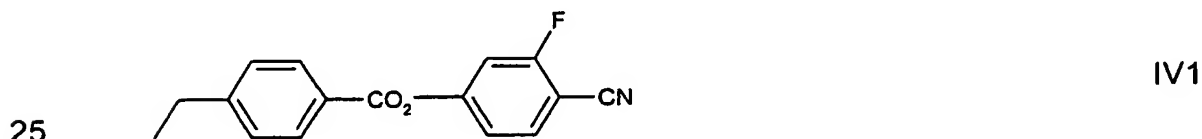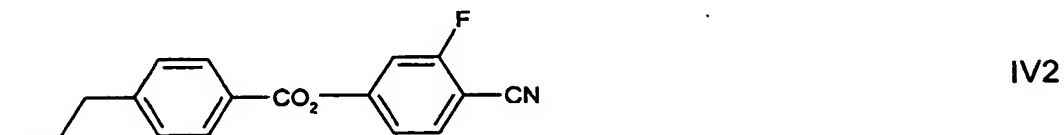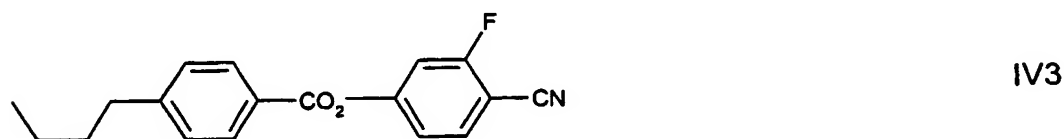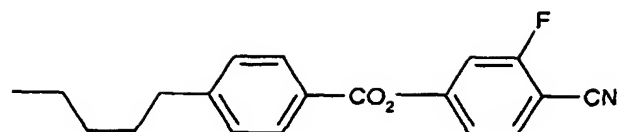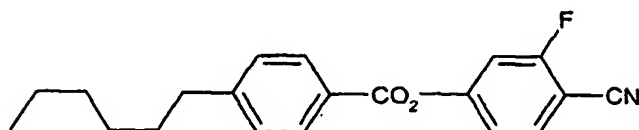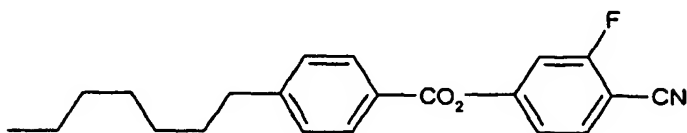
Among these compounds of formulas IV1 (having a dielectric anisotropy $\Delta\varepsilon$ of 53.7), IV2, IV3 ($\Delta\varepsilon$ = 44.9) and IV4 ($\Delta\varepsilon$ = 43.0) are most preferred. If present the total amount of compounds of formula IV in the liquid crystal composition for use in the zenithal bistable nematic devices of the invention may be about 10 weight% or more (although even smaller amounts are possible as well), preferably 20 weight% or more, more preferred in the range of about 25 to 60 weight%, still more preferred in the range of about 35 to about 55 weight%. When used as a mixture different compounds of formula IV may be contained in component (a) in an almost equal amount. For instance, if compounds of formulas IV1 to IV4 are used, they may be contained in an 1:1:1:1 ratio.

In another preferred embodiment of the invention component (a) of the liquid crystal composition for use in the zenithal bistable nematic devices comprises at least one compound of formula XV:

XV
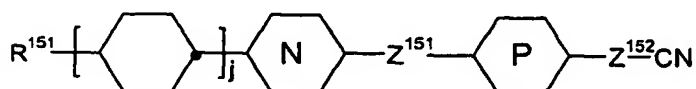
in which

j   is 0 or 1;

R^{151}　is C_1-C_{15} alkyl which is unsubstituted or mono- or poly-substituted with CN or halogen and in which one or more of the CH_2 groups may be replaced by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that there are no hetero atoms adjacent to each other;

Z^{151} and Z^{152} are independently of each other a single bond or -C≡C-;

is

is
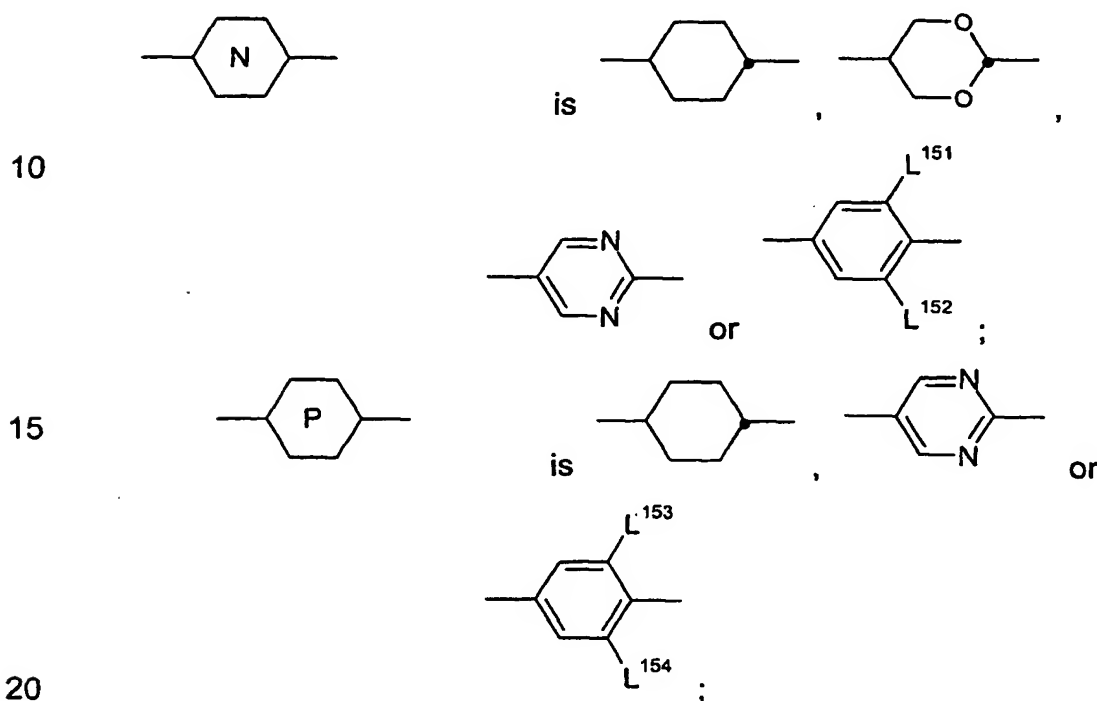
in which

L^{151}, L^{152}, L^{153} and L^{154} are independently of each other H or F.

Preferred classes of compounds comprised by formula XV are compounds of formula XV-A to XV-E in which Z^{151} is a single bond:

XV-A

XV-B

5

XV-C

10

XV-D

15
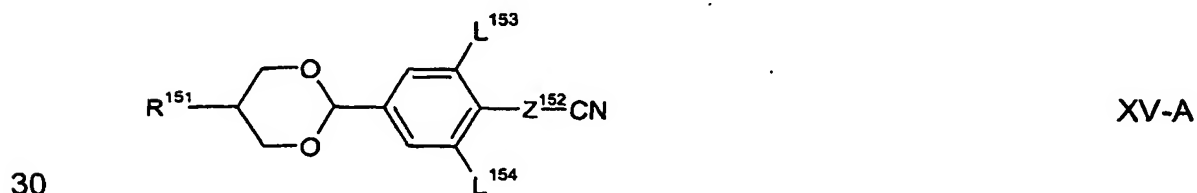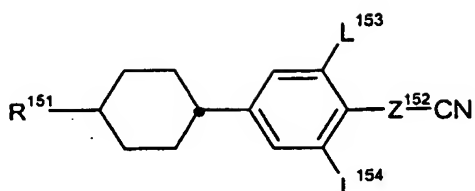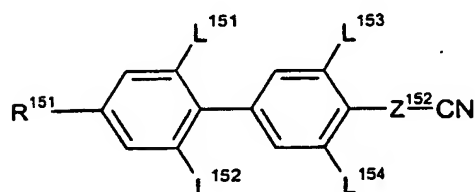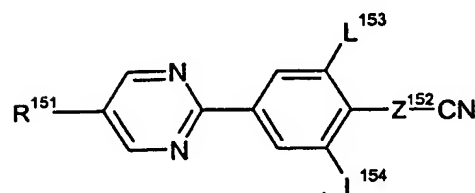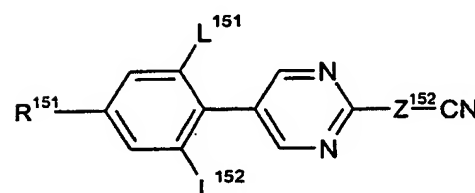
XV-E

in which R^{151} is defined as above and preferably means a straight-chain
20   alkyl with 1 to 8 carbon atoms, especially a straight-chain alkanyl or alkenyl
having 2, 3, 4, 5 or 6 carbon atoms; Z^{152} is a C≡C triple bond or preferably
a single bond; and L^{151}, L^{152}, L^{153} and L^{154} are H or F with L^{151} and L^{152}
being preferably H. Preferred compounds of formulas XV-A to XV-E are

25   XV-A1

XV-A2

30

5

XV-A3

XV-B1

10

XV-B2

XV-B3

15

XV-C1

XV-C2

20

XV-C3

25
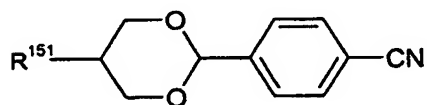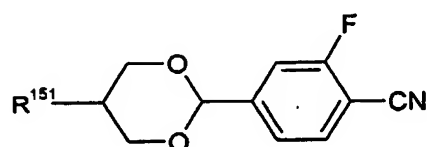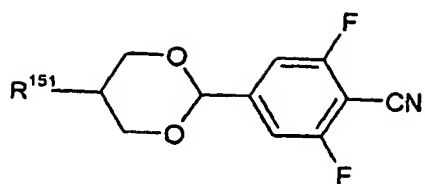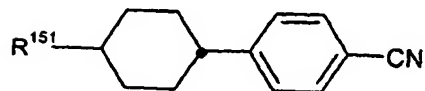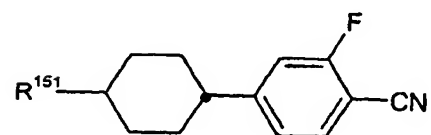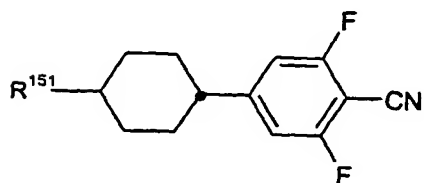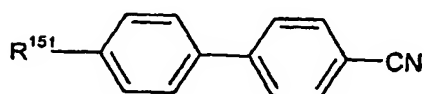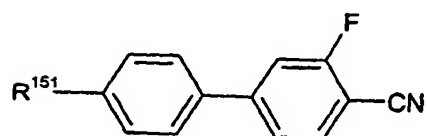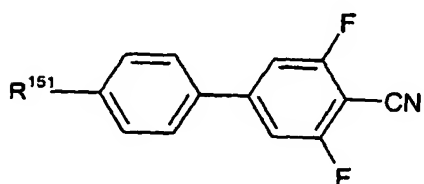
30

IX-D1

5

IX-D2

10

IX-E1

IX-E2

15
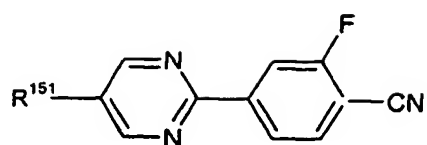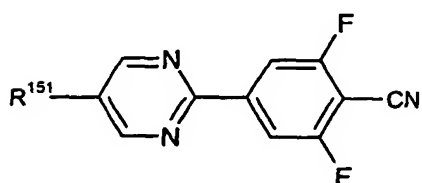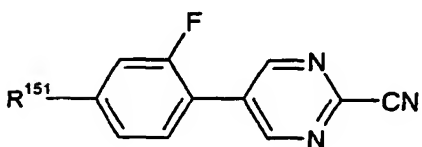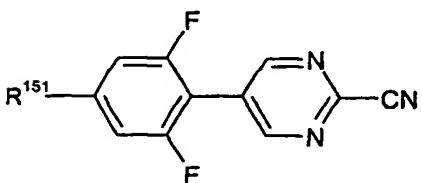
in which R^{151} is as defined above.

Some specific examples of compounds of formula XV are

20
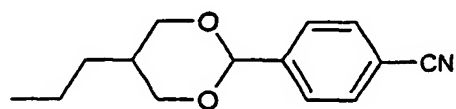
XV1

25
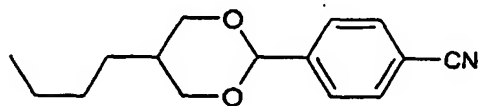
XV2
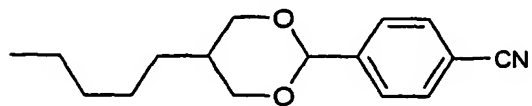
XV3

30
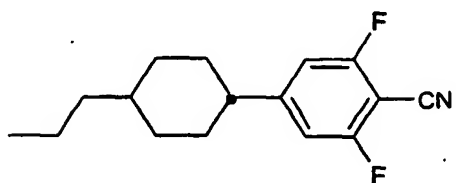
XV4

If these compounds are present in component (*a*) their total amount may range from about 5 to about 45 weight%. It is preferred that only one type of compounds of formulas XV-A to XV-E are present in the liquid crystal composition for use in the invention for the same time.

In a further preferred embodiment of the invention the liquid crystal composition for use in a bistable liquid crystal device and especially in a zenithal bistable nematic liquid crystal device may also comprises a component (*β*). Said component (*β*) may be present in the liquid crystal composition in an amount of at least 5 weight% or more. Component (*β*) may positively influence the clearing point of the liquid crystal compositions used in bistable liquid crystal devices, i.e. the clearing point may be increased by adding component (*β*). Component (*β*) comprises compounds of formula V and/or formula VI and/or formula VII and/or formula VIII and/or formula IX

$$R^{51}-\left\langle C \right\rangle-\left\langle D \right\rangle-\left\langle\hspace{-0.3em}\rule{0pt}{1ex}\hspace{-0.3em}\right\rangle-\left\langle E \right\rangle-R^{52} \qquad\qquad V$$
$$\underset{L^{51}}{}$$

$$R^{61}-\left[\left\langle\hspace{-0.3em}\right\rangle\right]_g-\left\langle\hspace{-0.3em}\right\rangle-Z^{61}-\left\langle F \right\rangle-\left\langle\hspace{-0.3em}\right\rangle-R^{62} \qquad VI$$

$$R^{71}-\left\langle\hspace{-0.3em}\right\rangle-\left\langle\hspace{-0.3em}\right\rangle\equiv\left\langle\hspace{-0.3em}\right\rangle-R^{72} \qquad\qquad VII$$

$$R^{81}-\left\langle\hspace{-0.3em}\right\rangle-CH{=}CH-\left\langle\hspace{-0.3em}\right\rangle-\left\langle\hspace{-0.3em}\right\rangle-R^{82} \qquad VIII$$
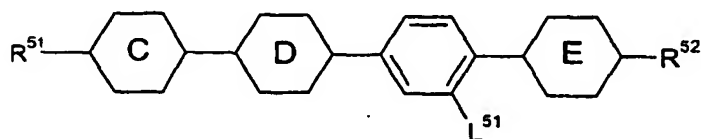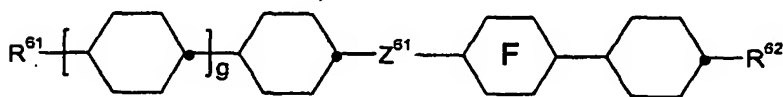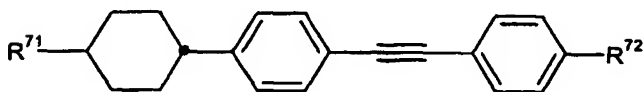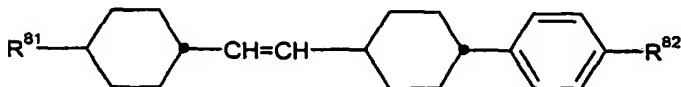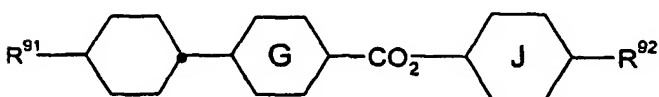
$$R^{91}-\left\langle\hspace{-0.3em}\right\rangle-\left\langle G \right\rangle-CO_2-\left\langle J \right\rangle-R^{92} \qquad IX$$

in which

g   is 0 or 1;

R^{51}, R^{52}, R^{61}, R^{62}, R^{71}, R^{72}, R^{81}, R^{82}, R^{91} and R^{92} are independently
of each other C_1-C_{15} alkyl which is unsubstituted or mono- or
poly-substituted with CN or halogen and in which one or more
of the CH_2 groups may be replaced independently of each
other by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that
there are no hetero atoms adjacent to each other;

L^{51} is H or F;

Z^{61} is -CO-O-, -CH₂O-, -OCH₂-, -CF₂O-, -OCF₂-, -CH₂CH₂-,
-CF₂CF₂-, -CH₂CF₂-, -CF₂CH₂-, -CH=CH- or -C≡C-;

—⟨C⟩—   ,   —⟨F⟩—   ,   —⟨G⟩—   and   —⟨J⟩—

are independently of each other   ⟨cyclohexane⟩   or

⟨benzene⟩ ;

—⟨D⟩—   is   ⟨cyclohexane⟩   or   ⟨benzene-L^{52}⟩ ;

—⟨E⟩—   is   ⟨cyclohexane⟩   or   ⟨benzene-L^{53}⟩ ;
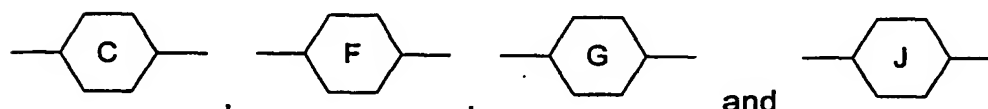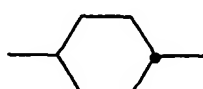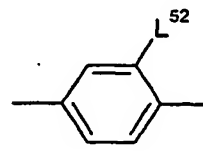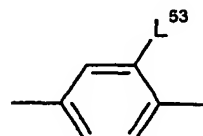
in which
L^{52} and L^{53} are independently of each other H or F.

Preferred compounds of formula V are of the following formulas:

V-A

V-B

V-C

V-D

V-E

V-F

V-G
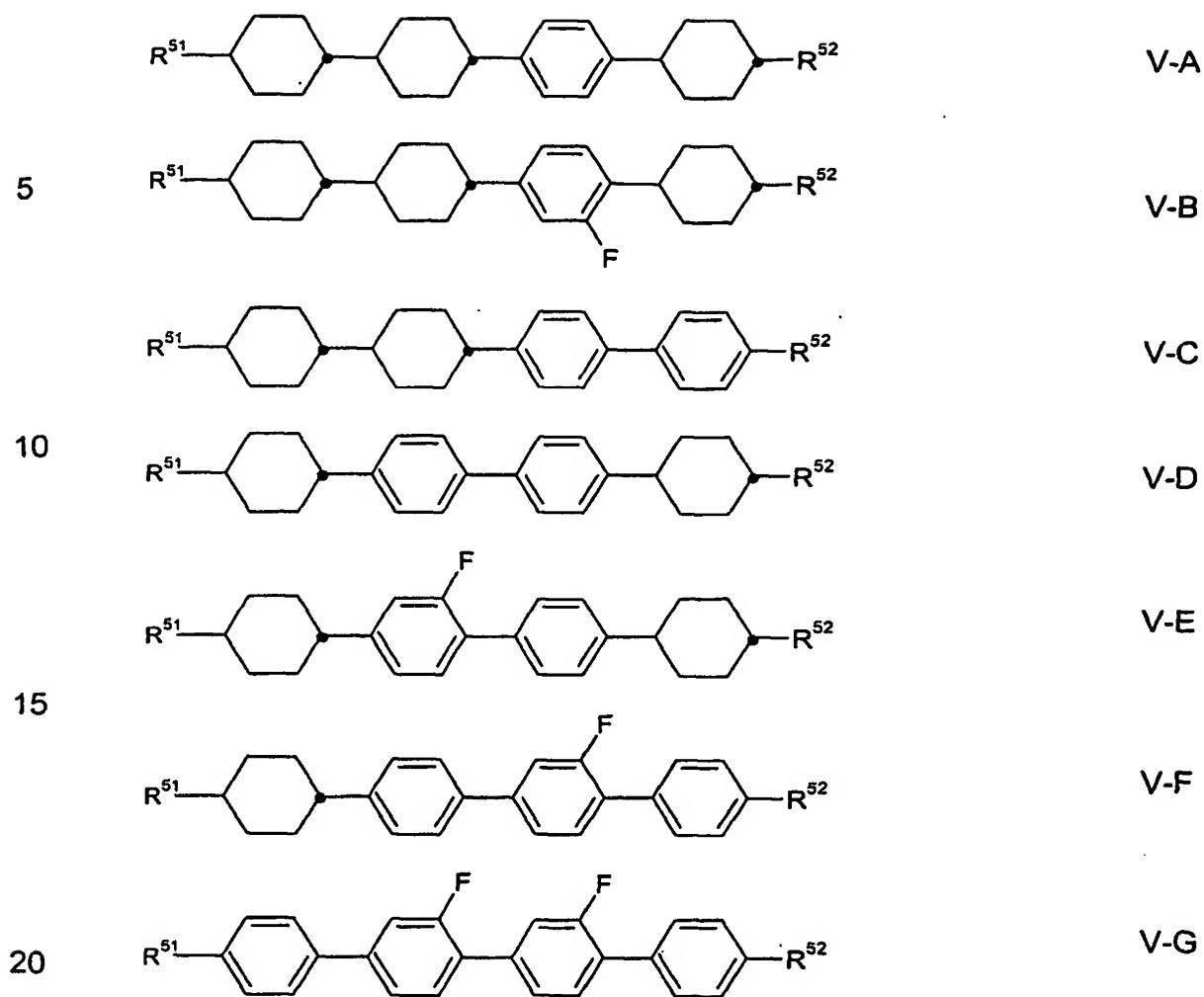
with R^{51} and R^{52} being as defined above. Preferably, in formulas V and V-A to V-G R^{51} and R^{52} are both independently of each other straight-chain alkyl, more preferred straight-chain alkanyl or alkenyl having 2, 3, 4, 5 or 6 carbon atoms, especially straight-chain alkanyl with 2 to 6 carbon atoms, a is 1 and L^{51} is H or F (for formula V). Highly preferred compounds are of formula V-D and V-E. Especially preferred examples of formula V are compounds of formula V1 to V6:

V1

5

V2

V3

10

V4

V5

15

V6
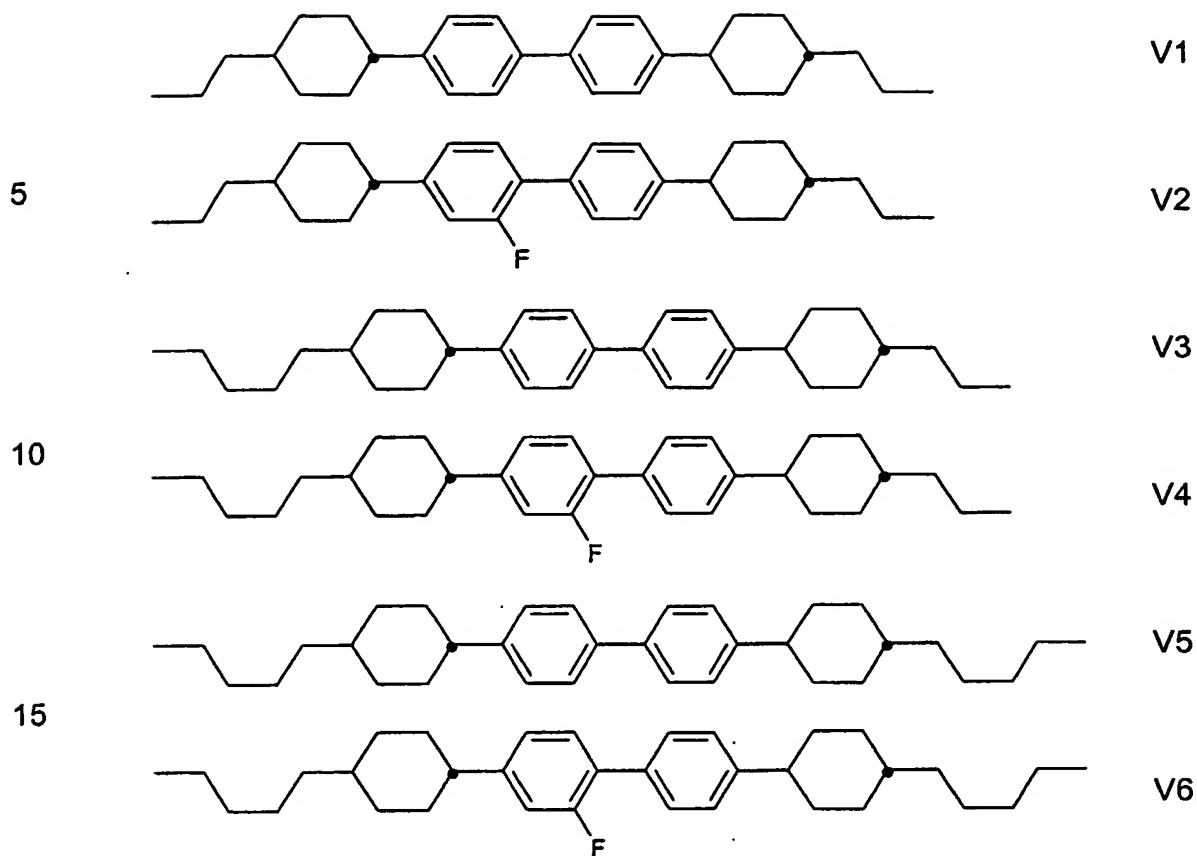
20   Most preferred compounds of formula V are compounds V2, V4 and V6, and it is preferred to have a mixture of all three compounds in the liquid crystal composition.

With respect to formula VI preferred compounds are of formulas VI-A and

25   VI-B in which g is 1 as well as of formulas VI-C and VI-D in which g is zero:

VI-A

30

VI-B

- 42 -

VI-C

·VI-D
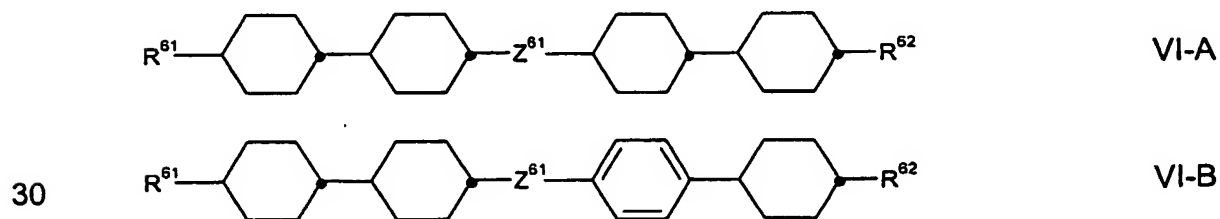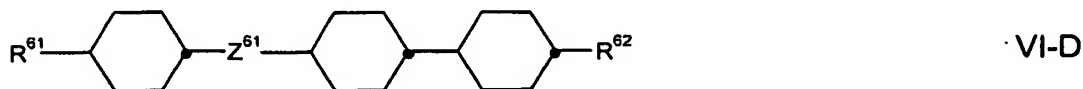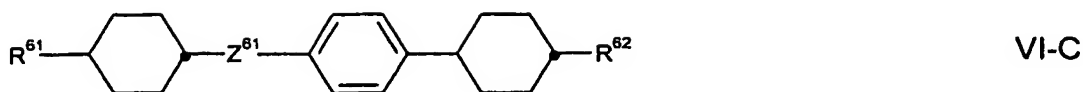
with R^{61}, R^{62} and Z^{61} being as defined above; Z^{61} is preferably -CO-O- or, in case of formula VI-D, -OCH$_2$-. R^{61} and R^{62} are preferably both independently of each other straight-chain alkyl, more preferred straight-chain alkanyl or alkenyl having 2, 3, 4, 5 or 6 carbon atoms, especially straight-chain alkanyl with 2 to 6 carbon atoms. Compounds of formula VI-B are more preferred. Especially preferred examples of formula VI are compounds of formulas VI1 to VI3 as well as of formulas VI4 and VI5 and of formulas VI6 to VI8:

VI1

VI2

VI3

VI4

VI5

VI6

VI7

VI8
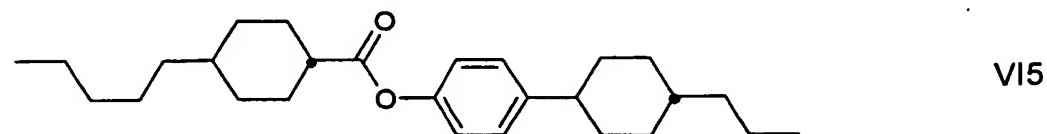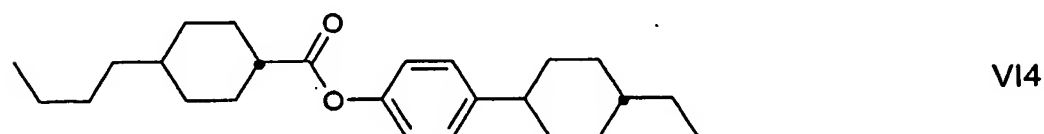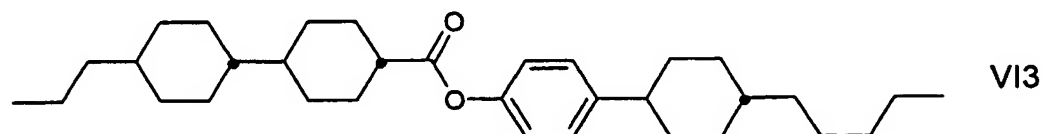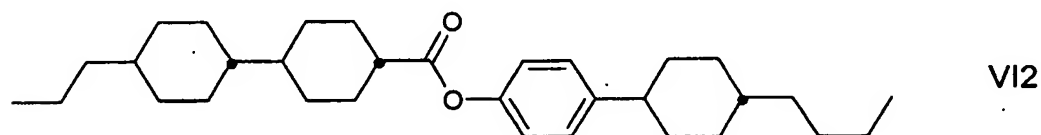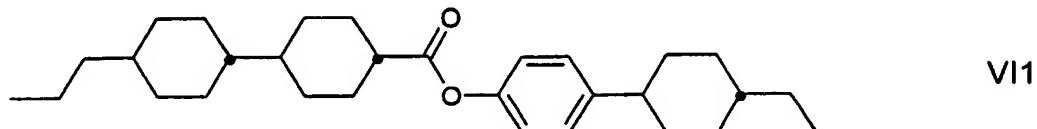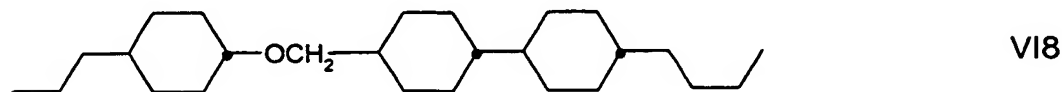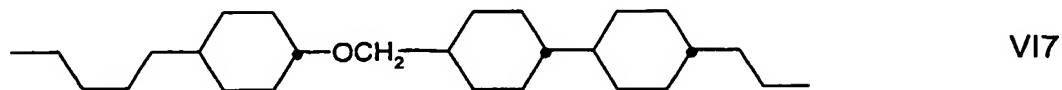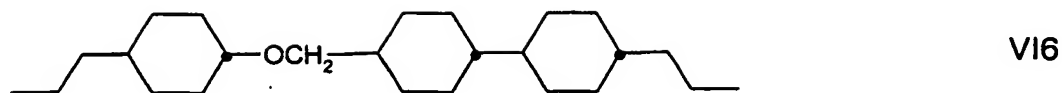
It is especially preferred to have a mixture of compounds VI1, VI2 and VI3 in the liquid crystal composition.

Preferably, in formula VII R^{71} is straight-chain alkyl, especially straight-chain alkanyl having 2, 3, 4, 5 or 6 carbon atoms, and R^{72} is straight-chain alkyl or, more preferred, alkoxy having 1, 2, 3 or 4 carbon atoms. Especially preferred examples of formula VII are compounds of formula VII1 to VII6:

VII1

VII2

VII3

VII4

VII5

VII6

- 44 -
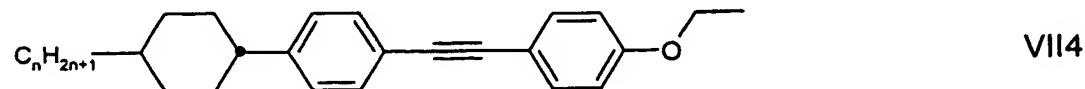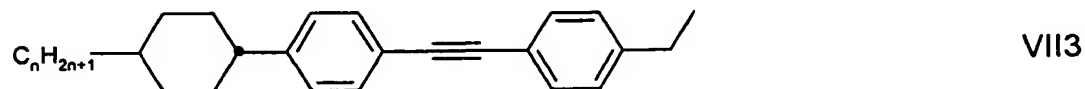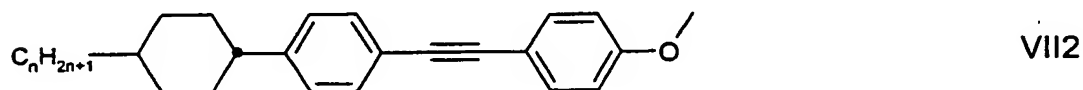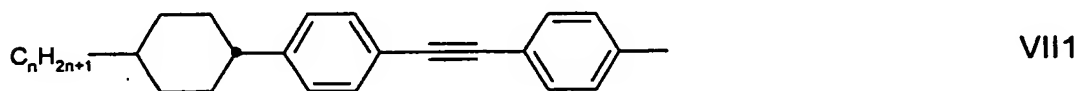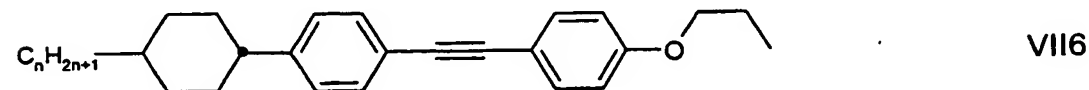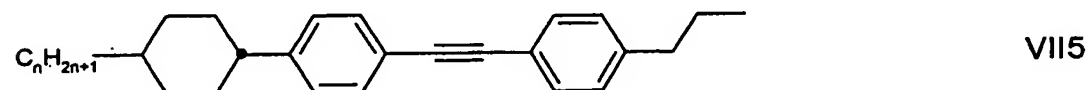
in which n is an integer from 1 to 6, preferably 2, 3 or 4, especially 3. Preferred compounds of formula VII are compounds of formula VII2, VII4 and VII6 with n = 3 (giving an n-propyl substituent). It is preferred to have a mixture of all three compounds VII2, VII4 and VII6 in the liquid crystal

5   composition.

Preferably, in formula VIII R^{81} is straight-chain alkenyl, especially straight-chain alkenyl having 2, 3, 4 or 5 carbon atoms, and R^{82} is straight-chain alkanyl or alkoxy both having 1, 2, 3, 4 or 5 carbon atoms (formula VIII-A or

10   VIII-B with n = 2, 3, 4, 5 and m = 1, 2, 3, 4, 5).

VIII-A

15

VIII-B
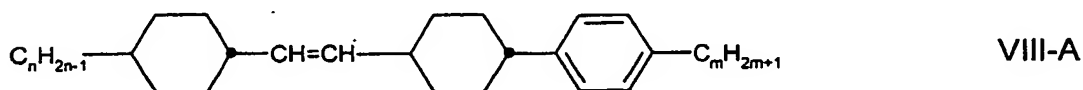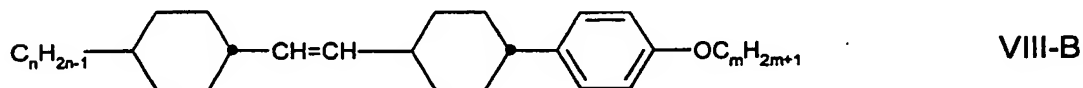
Preferred compounds of formula VIII are compounds of formula VIII1 to VIII4:

20

VIII1

25

VIII2

VIII3

30
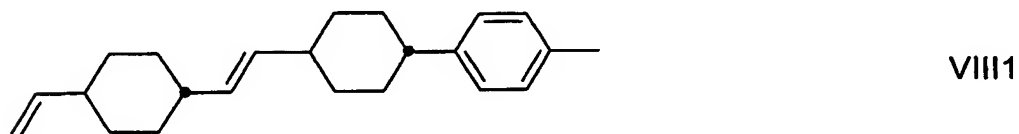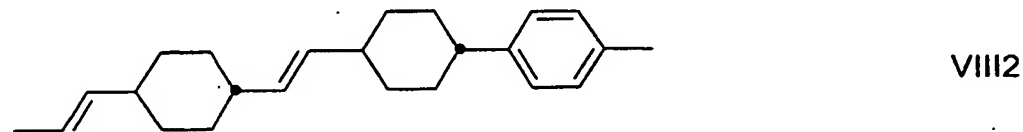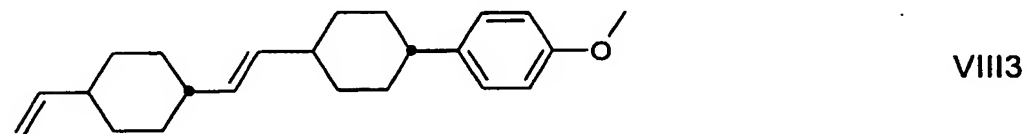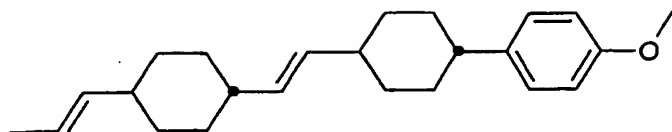
VIII4

Especially preferred are compounds of formula VIII1, VIII3 and VIII4. They
may be used alone or, more preferred, as a mixture of two or three
compounds.

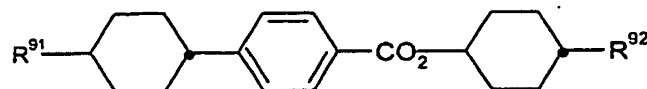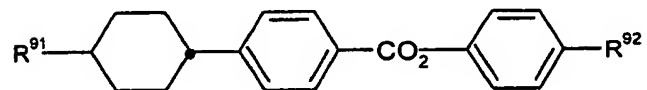Regarding compounds of formula IX specific compounds are of the
following formulas

IX-A

IX-B

IX-C
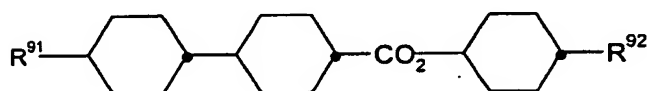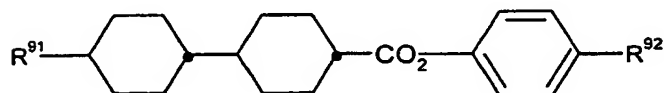
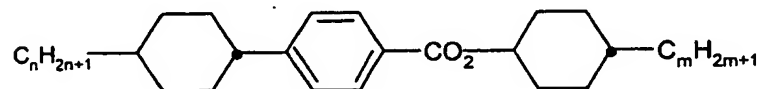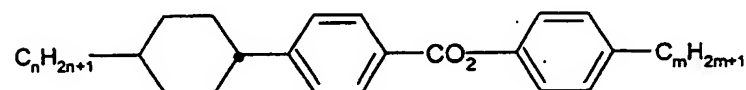IX-D

with R^{91} and R^{92} being as defined above. Preferably, R^{91} and R^{92} are
straight-chain alkyl; especially alkanyl, with 1, 2, 3, 4, 5 or 6 carbon atoms.
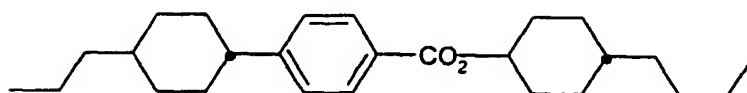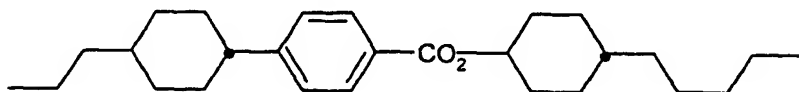Preferred compounds of formula IX are:

IX-C1

IX-D1

with n and m being independently of each other 1, 2, 3, 4, 5 or 6. Especially preferred examples of compounds of formula IX are
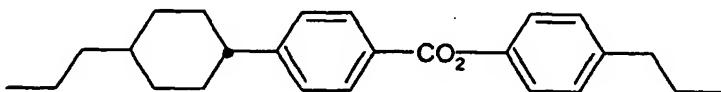
5

IX-1

IX-2
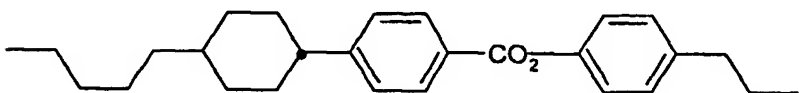
10

IX-3

IX-4

15

Component (β) may be used in an amount of 5 weight% or more in the liquid crystal composition for use in bistable liquid crystal devices according to the invention. When component (α) comprises at least one compound of formula III, it is preferred that the liquid crystal composition comprises 8
20   weight% or more of component (β). When there is no compound of formula II in component (α), an amount of at least 10 weight% of component (β) is even more preferred. In certain embodiments of the invention a total amount of 15 or 20 or more weight% of component (β) is highly preferred.

25   In an actual embodiment of the invention component (β) may contain one or more compounds of only one of the formulas V or VI or VII or VIII or IX. It is also possible that it contains one or more compounds of two, three or more of the formulas V to IX. It may contain an equal or a different amount of compounds of each formula used. It is preferred that component (β)
30   contains one or more compounds of one or two of the formulas V, VI, VII, VIII or IX. If compounds of two of the formulas V to IX are contained, any combination is possible. Both types of compounds may be used in an equal

amount, or one of the types may be used in an excess with regard to the other one, for instance, in a ratio of 2:1. It is preferred that an equal amount of both types of compounds is used. When component (α) comprises no compound of formula II, it is preferred that component (β) comprises

5   compounds of two of the formulas V, VI, VII, VIII or IX.

In another preferred embodiment of the invention the liquid crystal composition for use in the bistable liquid crystal device and especially in the zenithal bistable nematic device according to the invention further

10   comprises 3 weight% or more of a component (γ) containing one or more compounds having an optical anisotropy Δn of at least 0.20. It has been found that the use of this component (γ) may decrease the operating voltage V_{opt} of the liquid crystal composition. In general, component (γ) can comprise any (mesogenic) compound exhibiting a Δn of at least 0.20 that is

15   not detrimental to the set of parameters important for use in especially zenithal bistable nematic liquid crystal devices. It is preferred that component (γ) comprises tolanes having a Δn of at least 0.20, especially at least one tolane compound of formula X:
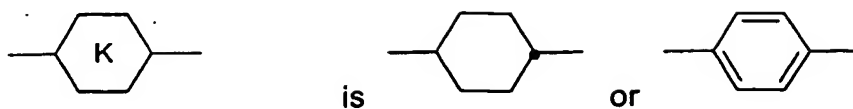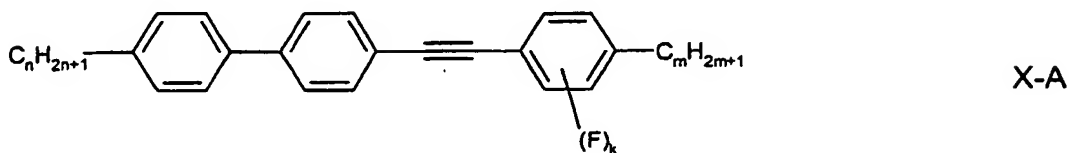
20

X
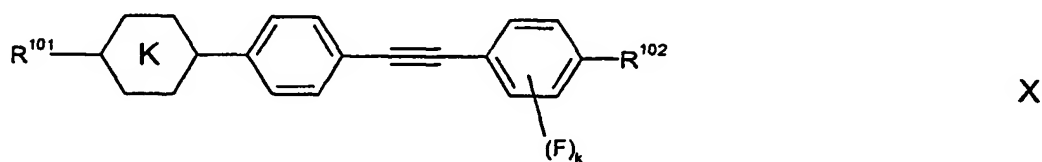
in which

25   k   is 0, 1 or 2;

R^{101} and R^{102} are independently of each other C_1-C_{15} alkyl which is unsubstituted or mono- or poly-substituted with CN or halogen and in which one or more of the CH_2 groups may be replaced

30   by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that there are no hetero atoms adjacent to each other; and
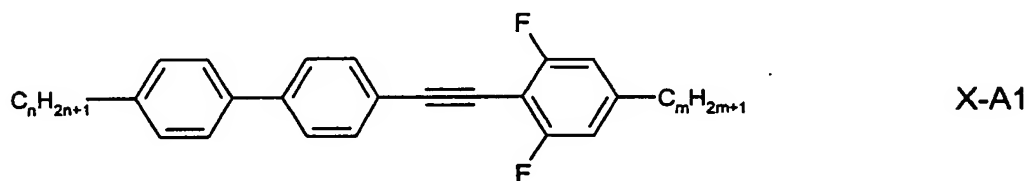
is   or

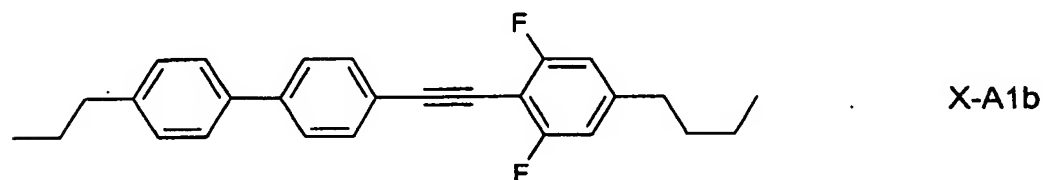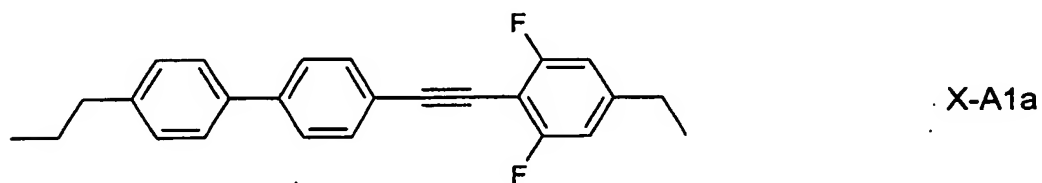5   Especially preferred are compounds of formula X-A

X-A

10

in which n and m are independently of each other 1, 2, 3, 4, 5 or 6 and k is
0, 1 or preferably 2. Preferred examples are of formula X-A1 with n being 2,
3 or 4 and m being 1, 2, 3, 4 or 5:

15

X-A1

20   Among these compounds X-A1a and X-A1b are most preferred:

X-A1a

25

X-A1b

30

It should be noted that certain compounds of formula X as well as compounds having a structure similar to that of formula X in that R^{102} is replaced by a fluorine atom may also have a ratio of $\gamma_1/T_{NI}{}^K$ of 0.51 mPa·s/K or less, a clearing point T_{NI} of at least 100 °C and a rotational viscosity γ_1 of not more than 190 mPa·s. Those may be comprised by component (δ). Among these compounds are, for instance, the compound of formula X-A1b ($\gamma_1/T_{NI}{}^K$ = 0.16; T_{NI} = 219 °C; and γ_1 = 81 mPa·s); and the compound having a structure similar to structure X-A1b in which the butyl substituent on the right-hand ring has been replaced by F ($\gamma_1/T_{NI}{}^K$ = 0.19; T_{NI} = 189 °C; and γ_1 = 89 mPa·s).

If present component (γ) is contained in an amount of at least 3 weight% and more preferred at least 5 weight%. Even much higher amounts of, e.g., up to 50 weight% of component (γ) may be used in specific embodiments of the invention in order to achieve, for instance, very fast switching.

The liquid crystal composition for use in the bistable liquid crystal devices and especially in the zenithal bistable nematic liquid crystal devices of the invention may comprise further substances for adjusting several properties of said composition if desired. For example, some of these substances may be used for adjusting the viscosity of the liquid crystal composition. (Hence, if one of these compounds has a ratio of $\gamma_1/T_{NI}{}^K$ of 0.51 mPa·s/K or less, a clearing point T_{NI} of at least 100 °C and a rotational viscosity γ_1 of not more than 190 mPa·s , it may be a compound being comprised by component (δ).) In certain embodiments the liquid crystal composition for use in the zenithal bistable nematic devices according to the invention comprises at least one compound of formula XI and/or at least one compound of formula XII and/or at least one compound of formula XIII and/or at least one compound of formula XIV
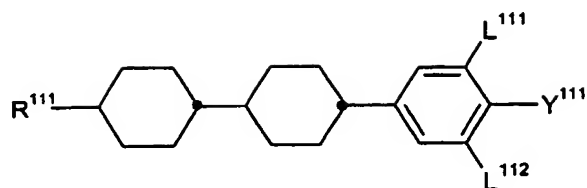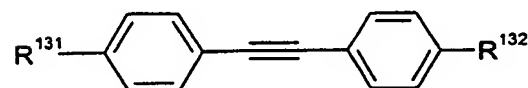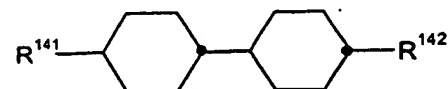
XI

5
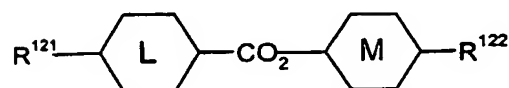
XII

XIII

10

XIV

in which

R^{111} and R^{142} are independently of each other C_2-C_{15} alkenyl which is unsubstituted or mono- or poly-substituted with CN or halogen and in which one or more of the CH_2 groups may be replaced independently of each other by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that there are no hetero atoms adjacent to each other;

R^{121}, R^{131}, R^{132} and R^{141} are independently of each other C_1-C_{15} alkyl which is unsubstituted or mono- or poly-substituted with CN or halogen and in which one or more of the CH_2 groups may be replaced independently of each other by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that there are no hetero atoms adjacent to each other;
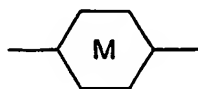
R^{122} is C_1-C_{15} alkyl which is unsubstituted or mono- or poly-substituted with halogen and in which one or more of the CH_2 groups may be replaced independently of each other by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that there are no hetero atoms adjacent to each other;

Y^{111} is F or Cl;

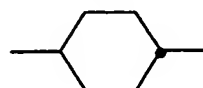L^{111} and L^{112} are independently of each other H or F; and
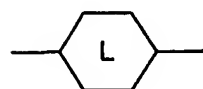
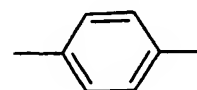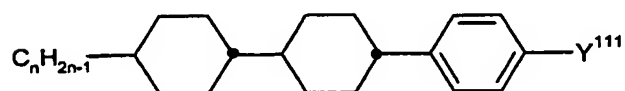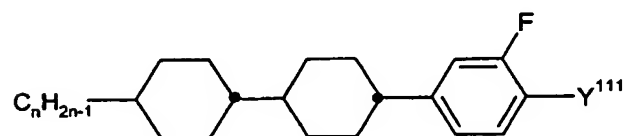 and are independently of each

other or .

The exact nature and amount of these compounds within the liquid crystal composition depend on the specific mixture and the desired effect and can be easily chosen by the skilled person.

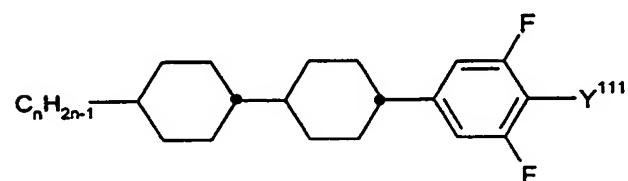Preferred compounds of formula XI are compounds of formula XI-A or XI-B
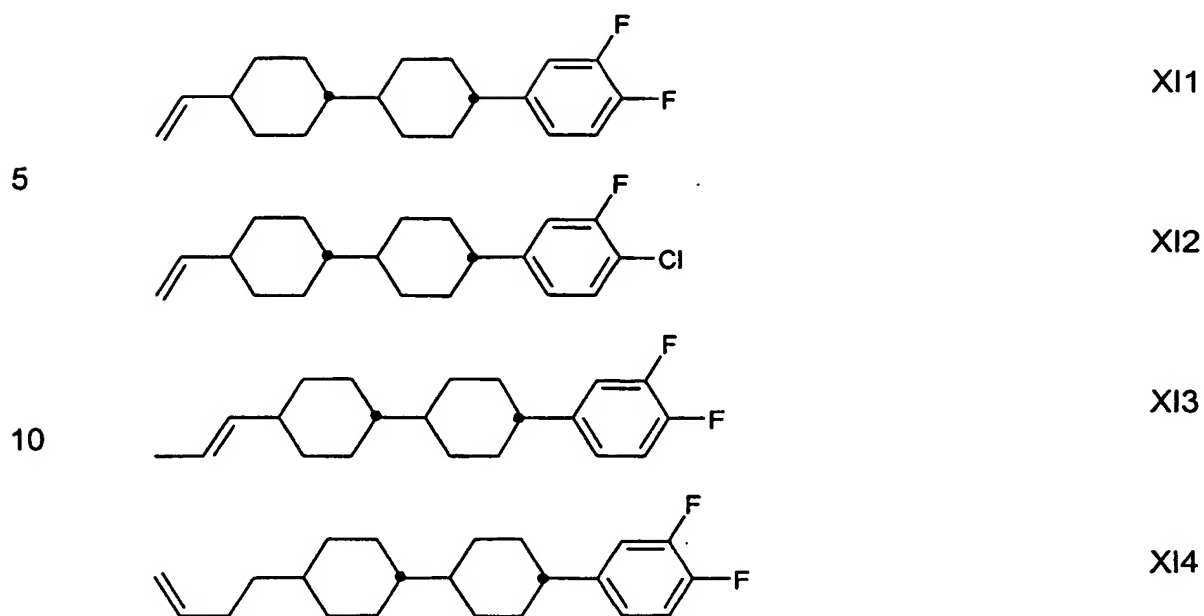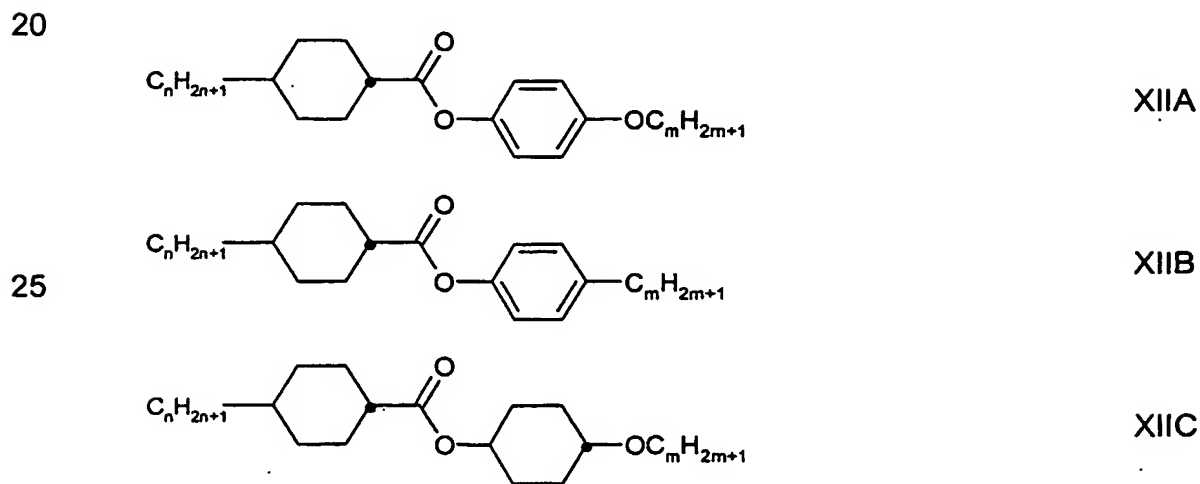
     XI-A

     XI-B

     XI-C

with n being 2, 3, 4, 5 or 6 and Y^{111} being F or Cl. Especially preferred compounds of formula XI are the following compounds:

XI1

5

XI2

XI3

10

XI4

15
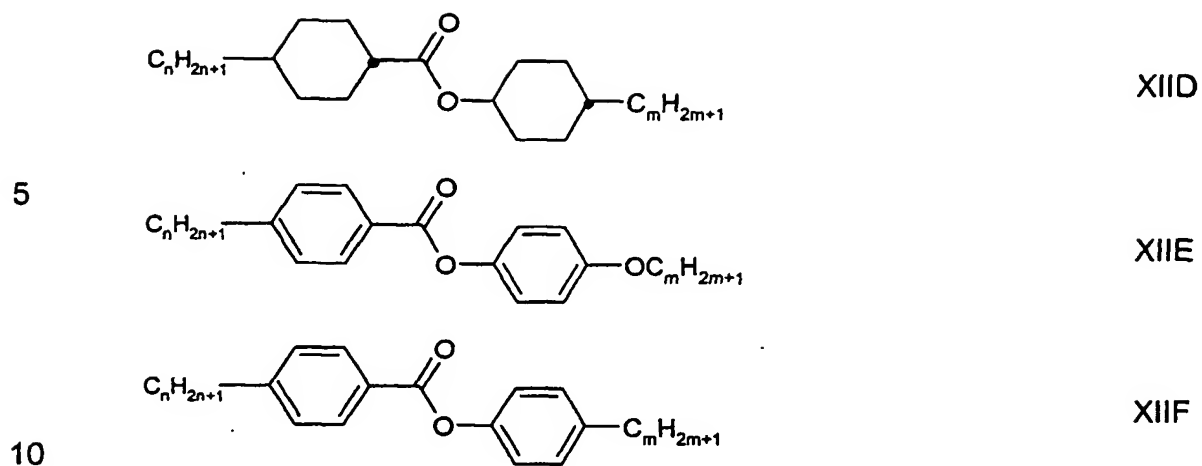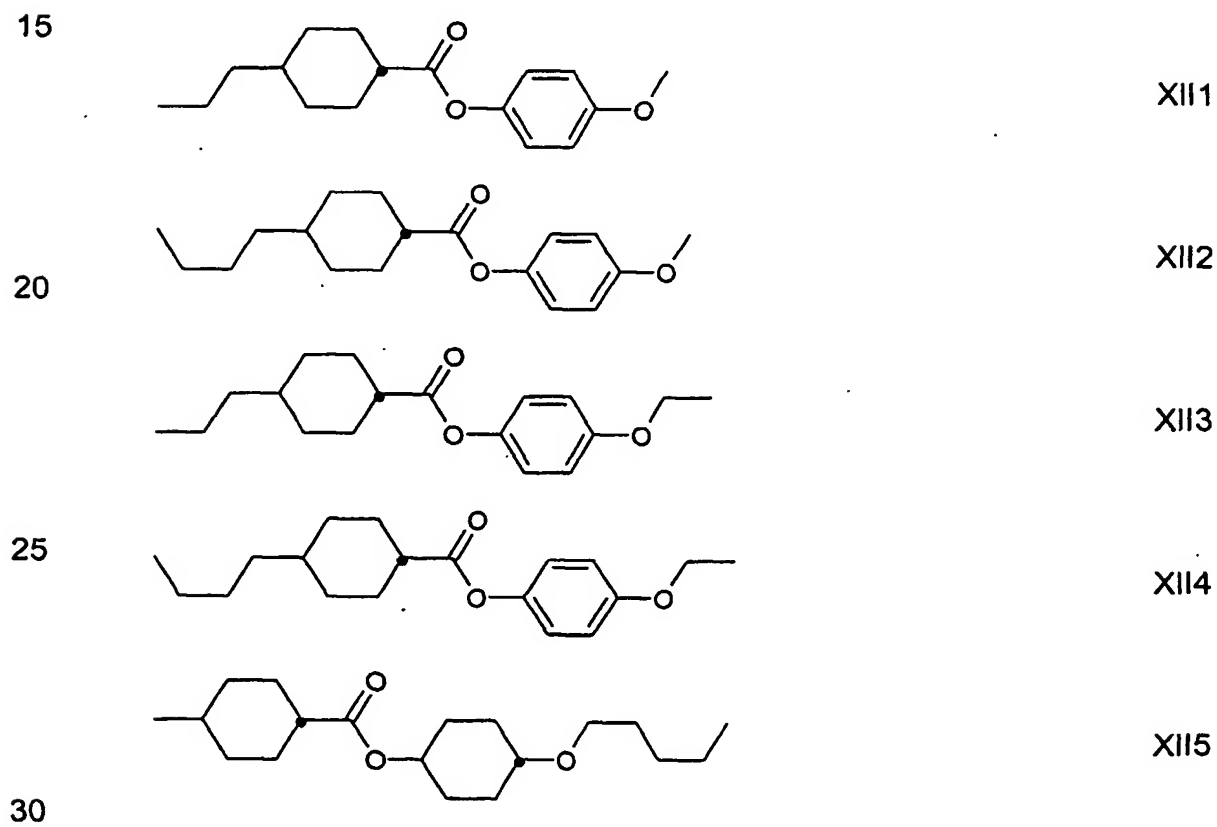
The most preferred compound of formula XI is compound XI1.

Preferred compounds of formula XII are compounds of formula XIIA, XIIB, XIIC, XIID, XIIE and XIIF:

20

XIIA

XIIB

25

XIIC

30

XIID

XIIE

XIIF

with n being 1, 2, 3, 4, 5 or 6 and m being 1, 2, 3, 4, 5 or 6. Specific examples of compounds of formula XII are the following compounds:

XII1

XII2

XII3

XII4

XII5

- 54 -

XII6

5

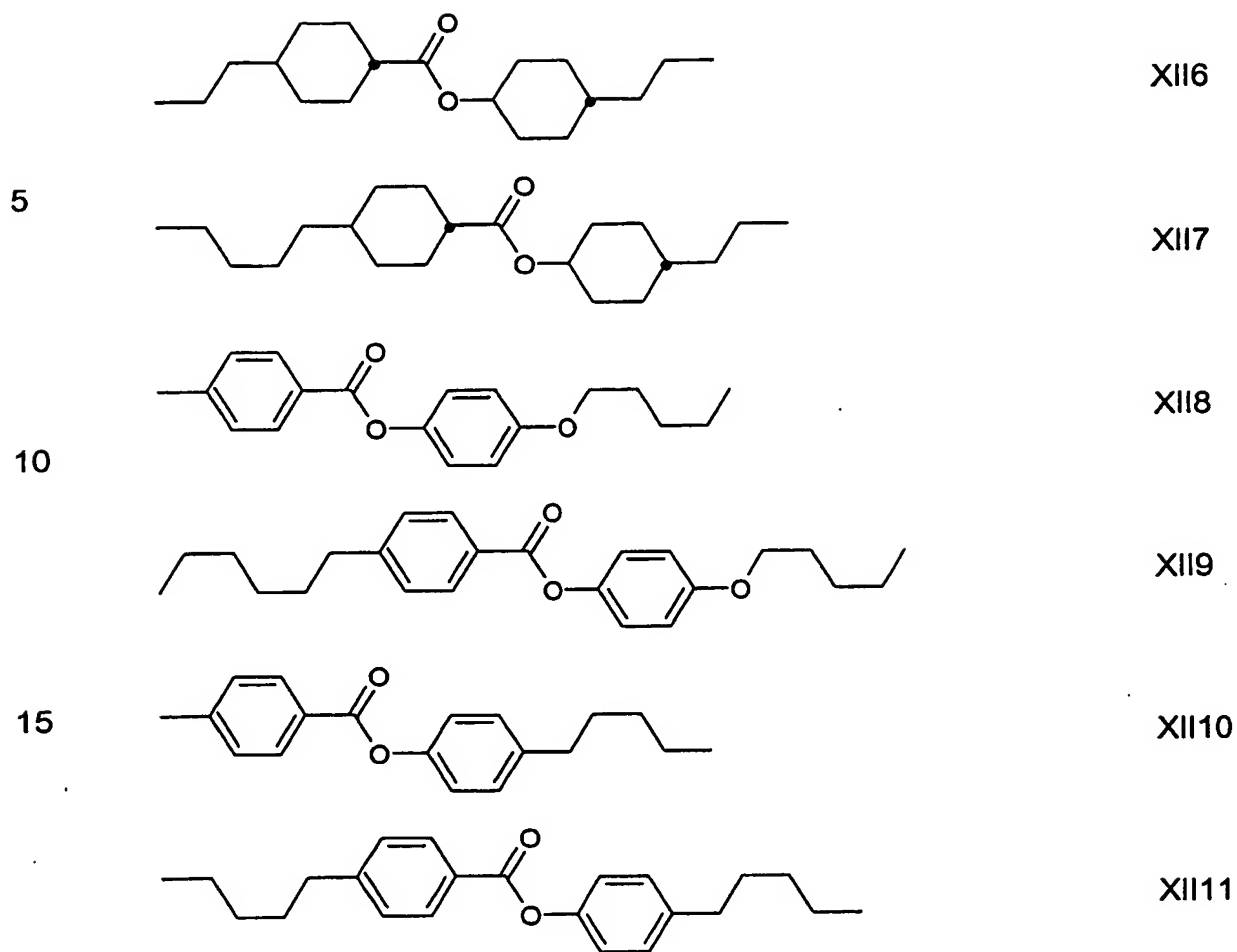XII7

XII8

10

XII9

15

XII10

XII11

20

Preferred compounds of formula XIII are compounds of formula XIIIA or XIIIB:

XIIIA

25

XIIIB

with n being 1, 2, 3, 4, 5, 6, 7 or 8 and m being 1, 2, 3, 4, 5 or 6. Especially
30   preferred examples of compounds of formula XIII are the following
compounds:

XIII1

XIII2

XIII3

XIII4

XIII5

XIII6

Preferred compounds of formula XIV are compounds of formula XIVA

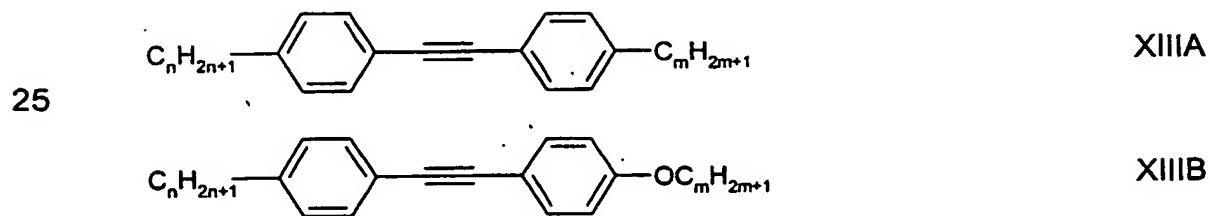$$C_nH_{2n+1}\text{—}\bigcirc\text{—}\bigcirc\text{—}C_mH_{2m-1}$$

XIVA

with n being 1, 2, 3, 4, 5, 6, 7 or 8 and m being 2, 3, 4, 5 or 6. Specific examples of compounds of formula XIV are the following compounds:
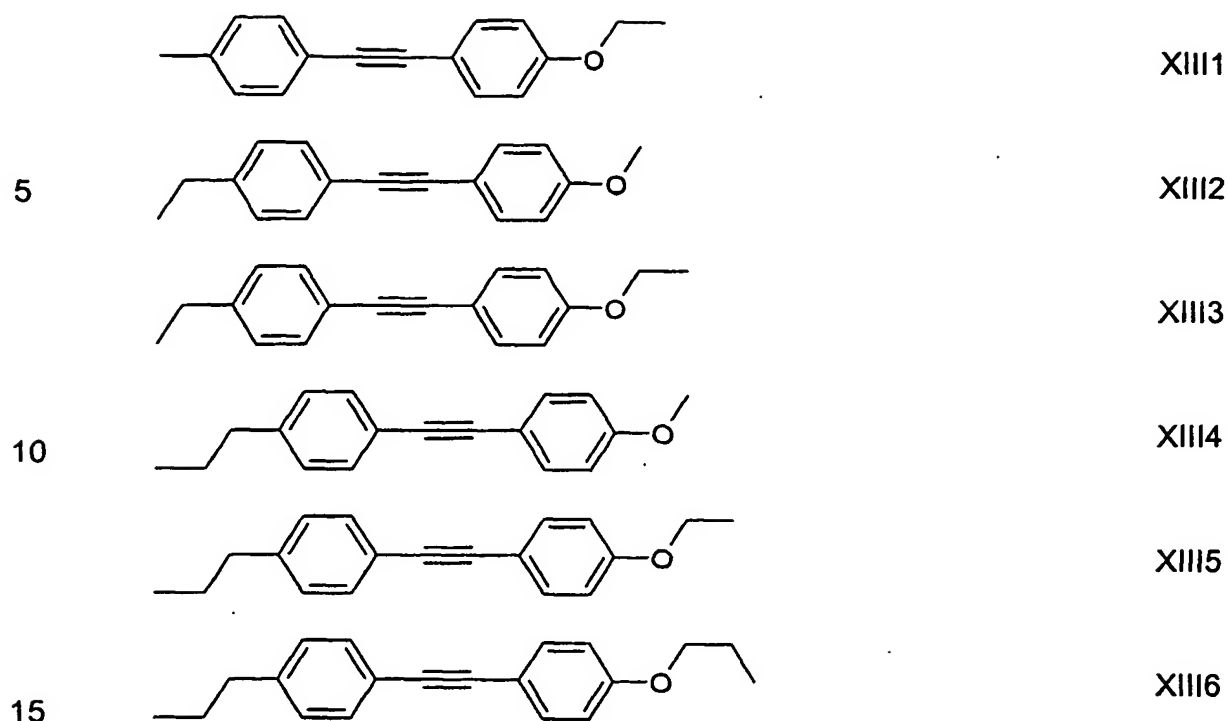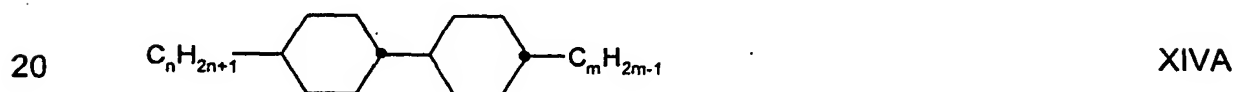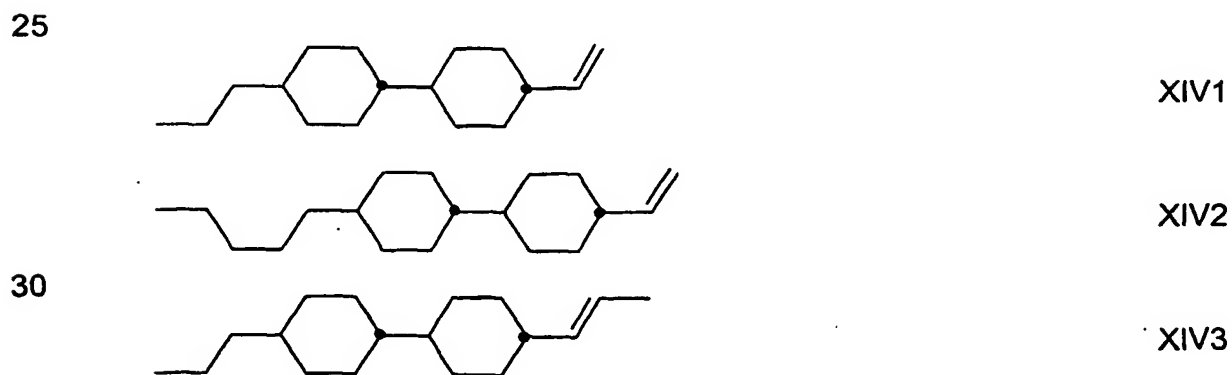

XIV1

XIV2
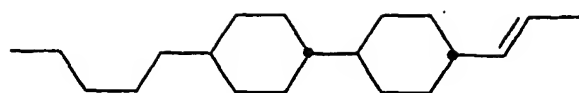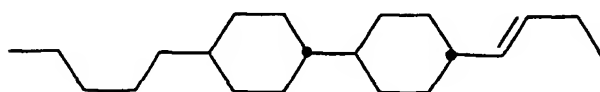

XIV3

XIV4

XIV5

The most preferred compound of formula XIV is compound XIV2.

The liquid crystal composition for the use according to the invention in the bistable liquid crystal devices may also comprises mesogenic substances having a medium dielectric anisotropy of $\Delta\varepsilon$ of about 8 to 10 or more, for instance one or more compounds of formula XVI and/or one or more compounds of formula XVII, preferably in an amount of up to 30 weight%, more preferred of up to 20 weight%:

XVI
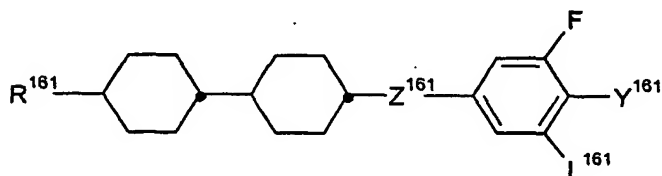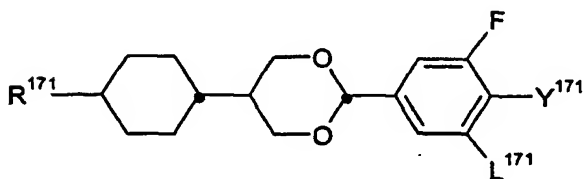
XVII

in which

R^{161} and R^{171} are independently of each other C_1-C_{15} alkyl which is unsubstituted or mono- or poly-substituted with CN or halogen and in which one or more of the CH_2 groups may be replaced independently of each other by -O-, -S-, -CH=CH-, -C$\equiv$C-, -CO-O-, -OC-O- such that there are no hetero atoms adjacent to each other;

Y^{161} and Y^{171} are independently of each other F, Cl, C_1-C_{15} alkanyl or C_2-C_{15} alkenyl that are mono- or poly-substituted with halogen, or C_1-C_{15} alkoxy, which is mono- or poly-substituted with halogen;

L^{161} and L^{171} are independently of each other H or F; and

Z^{161} is -CO-O-, CH_2O or CF_2O.

Preferably these compounds are of formulas XVI-A, XVI-B and XVII-A, respectively:
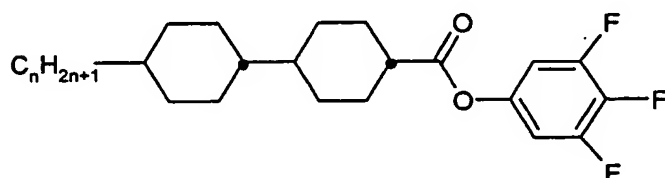
XVI-A
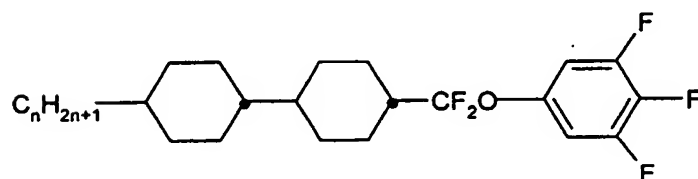
XVI-B
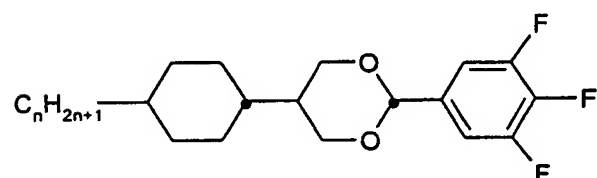
XVII-A

with n being in all three formulas 1, 2, 3, 4, 5, 6 or 7. These substances may influence both the operating voltage and the operating window of the liquid crystal composition for use in the zenithal bistable nematic devices of the invention as desired.

The liquid crystal composition for the use according to the invention in the zenithal bistable nematic liquid crystal devices may also comprises one or more of the mesogenic substances according to the following formulas XVIII to XXII. The exact nature and amount of these compounds within the

liquid crystal composition depend on the specific mixture and the desired effect and can be easily chosen by the skilled person.

XVIII

XIX

XX

XXI

XXII
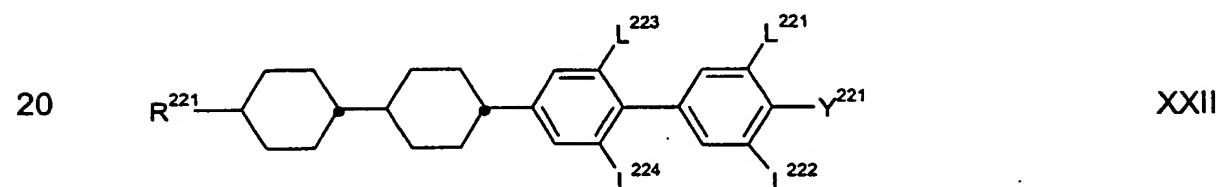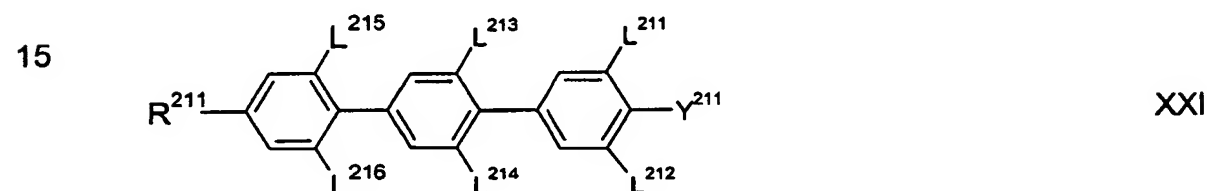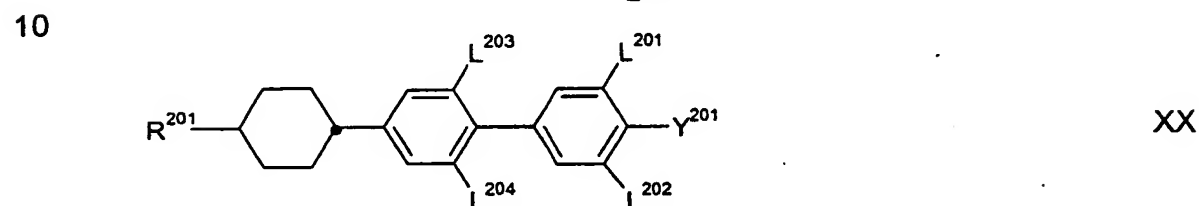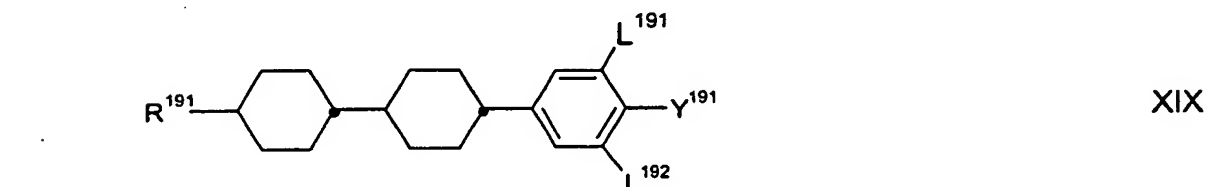
wherein

R^{181}, R^{182}, R^{201}, R^{211} and R^{221} are independently of each other C_1-C_{15} alkyl which is unsubstituted or mono- or poly-substituted with CN or halogen and in which one or more of the CH_2 groups may be replaced independently of each other by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that there are no hetero atoms adjacent to each other;

R^{191} is C$_1$-C$_{15}$ alkyl which is unsubstituted or mono- or poly-substituted with CN or halogen and in which one or more of the CH$_2$ groups may be replaced independently of each other by -O-, -S-, -C≡C-, -CO-O-, -OC-O- such that there are no hetero atoms adjacent to each other (i.e. R^{191} does not represent an alkenyl radical);

L^{191}, L^{192}, L^{201}, L^{202}, L^{203}, L^{204}, L^{211}, L^{212}, L^{213}, L^{214}, L^{215}, L^{216}, L^{221}, L^{222}, L^{223} and L^{224} are independently of each other H or F; and

Y^{191}, Y^{201}, Y^{211} and Y^{221} are independently of each other F, Cl, C$_1$-C$_{15}$ alkanyl or C$_2$-C$_{15}$ alkenyl that are independently of each other mono- or poly-substituted with halogen, or C$_1$-C$_{15}$ alkoxy which is mono- or poly-substituted with halogen.

Preferred compounds of formula XVIII are of the formula XVIIIA

C$_n$H$_{2n+1}$—⟨benzene ring⟩—⟨benzene ring⟩—C$_p$H$_{2p-1}$ XVIIIA
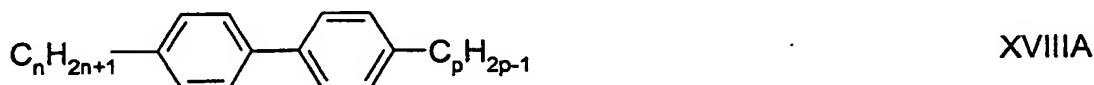
with n being 1, 2, 3, 4, 5, 6 or 7 and p being 2, 3, 4, 5, 6 or 7. More preferred are compounds of formula XVIIIA with n being 1, 2, 3, 4 or 5 and p being 2, 3, 4 and 5; especially preferred C$_n$H$_{2n+1}$ is methyl, ethyl or n-propyl and C$_p$H$_{2p-1}$ is a -CH$_2$-CH$_2$-CH=CH$_2$ or -CH$_2$-CH$_2$-CH=CH-CH$_3$ radical the latter preferably with E-configuration of the C=C double bond.

Preferred compounds of formula XIX are of the formulas XIXA and XIXB:

XIXA

5
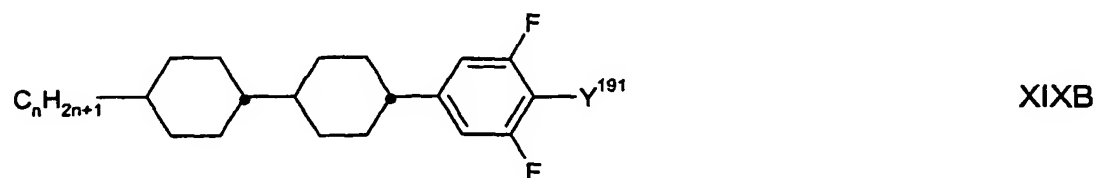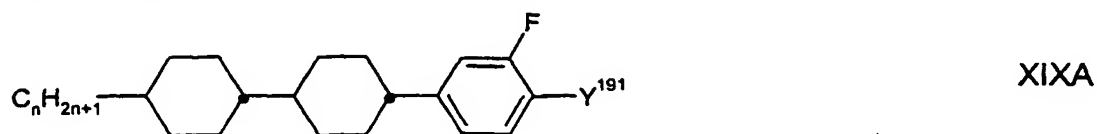
XIXB

10   with n being 1, 2, 3, 4, 5, 6 or 7 and Y^{191} being F, Cl, CF_3 or OCF_3. More
       preferred are compounds of formula XIXB with n being 2, 3, 4, 5, 6 or 7 and
       Y^{191} being F.

Preferred compounds of formula XX are of the formulas XXA to XXG:

15

XXA

XXB

20

XXC

25

XXD

30

XXE

XXF

XXG
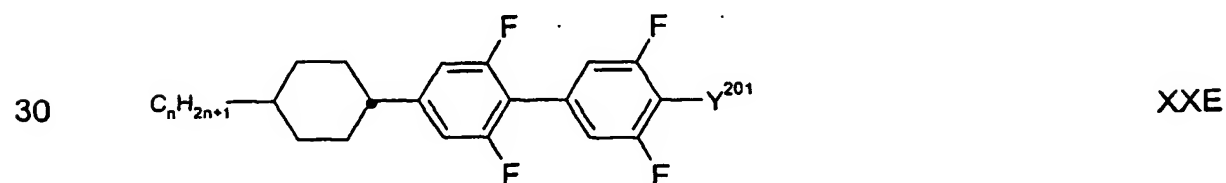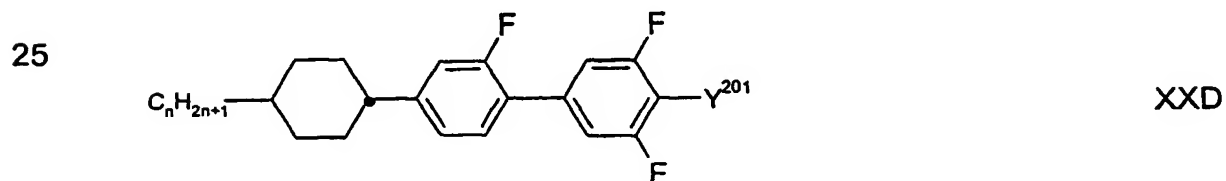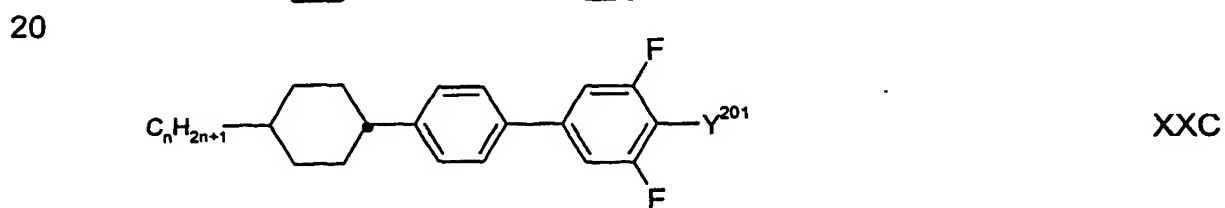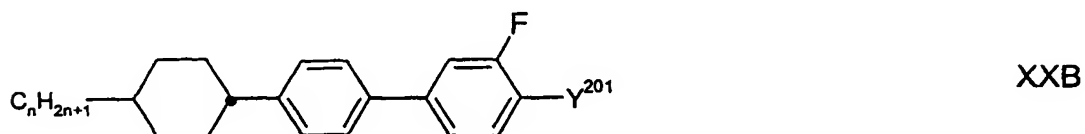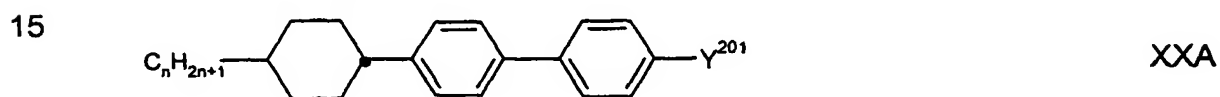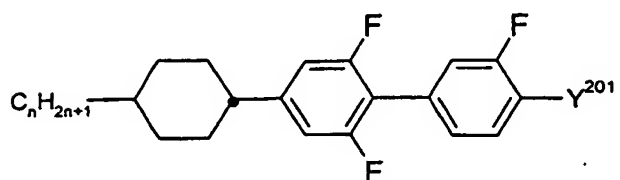
with n being 1, 2, 3, 4, 5, 6 or 7 and Y^{201} being F, Cl, CF_3 or OCF_3. More preferred are compounds of formulas XXB, XXC and XXD with n being 2, 3, 4, 5, 6 or 7 and Y^{201} being F.

Preferred compounds of formula XXI are of the formulas XXIA to XXIJ:
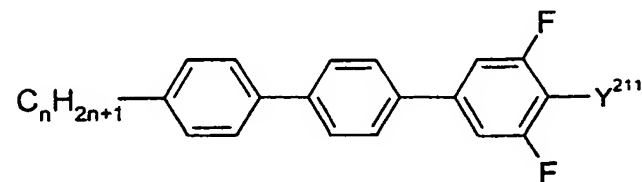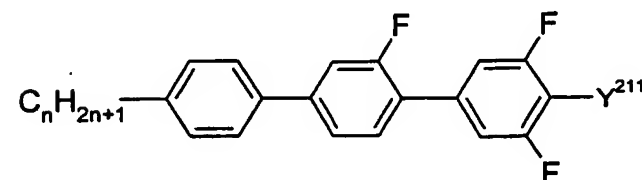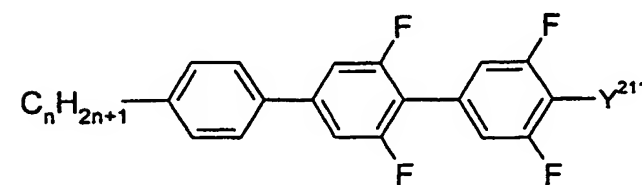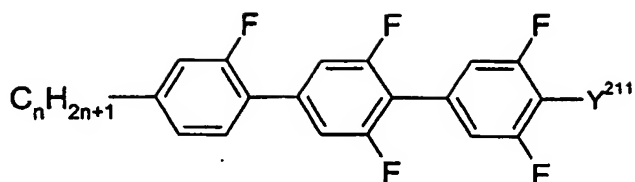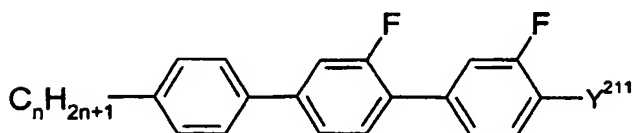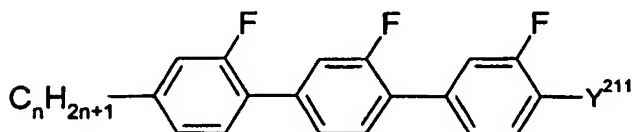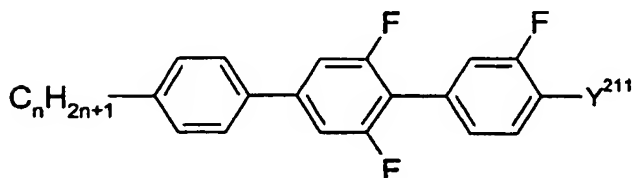
XXIA

XXIB

XXIC

XXID

XXIE

XXIF

XXIG

XXIH

XXIJ

with n being 1, 2, 3, 4, 5, 6 or 7 and Y^{211} being F, Cl, CF_3 or OCF_3. More preferred are compounds of formula XXID with n being 2, 3, 4, 5, 6 or 7 and Y^{211} being F.

Preferred compounds of formula XXII are of the formulas XXIIA or XXIIB:
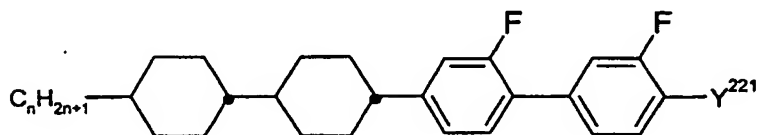
XXIIA
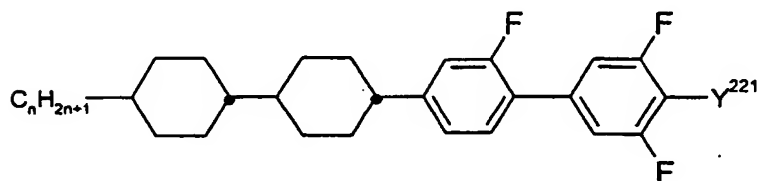
XXIIB

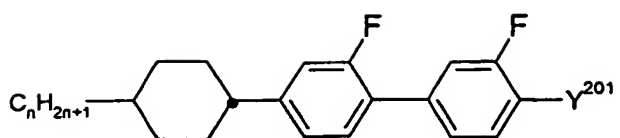with n being 1, 2, 3, 4, 5, 6 or 7 and Y^{211} being F, Cl, CF_3 or OCF_3. More preferred are compounds of formula XXIIB with n being 2, 3, 4, 5, 6 or 7 and Y^{221} being F.
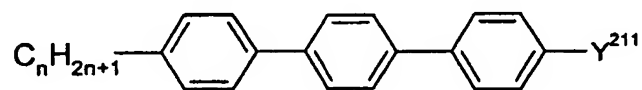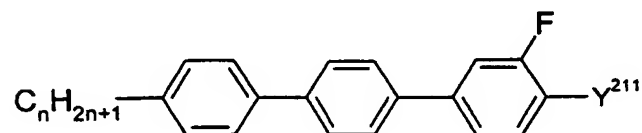
It is further preferred that the liquid crystal composition for the use of the invention is a nematic liquid crystal composition.

5   It will be acknowledged by those skilled in the art that the liquid crystal composition for the use according to the invention may also comprise further (mesogenic) compounds besides those disclosed in more detail in this specification. A wide variety of mesogenic compounds may be used as long as they are not detrimental to the set of parameters important for the

10   use of the bistable liquid crystal composition according to the invention.

A further subject matter of this invention is a liquid crystal medium comprising

- at least at least 30 weight% (based on the total weight of the

15   composition) of a component (a) containing one or more compounds having a dielectric anisotropy $\Delta\varepsilon$ of at least 25, whereby at least 25 weight% (based on the total weight of the composition) of said compounds have a dielectric anisotropy $\Delta\varepsilon$ of at least 40; and

20   - a component (δ) containing one or more compounds each having a ratio of γ_1/T_{NI}^K of 0.51 mPa·s/K or less, a clearing point T_{NI} of at least 100 °C and a rotational viscosity γ_1 of not more than 190 mPa·s (wherein γ_1 is the rotational viscosity at 20 °C in mPa·s and T_{NI}^K is the clearing point in degrees Kelvin).

25

A still further subject matter of the present invention is a liquid crystal medium comprising
- at least one compound of formula I; and
- at least one compound of formula II.

30   Said medium optionally comprises at least one compound of formula IV as defined above.

- 64 -

Still a further subject matter of the present invention is a liquid crystal medium comprising

- at least one compound of formula I; and

5
- at least one compound of formula III.

Said medium optionally comprises at least one compound of formula IV as defined above.

10   The liquid crystal composition for use in the zenithal bistable nematic devices of the invention may also contain an optically active component (ζ) as a dopant in an amount of 0 to 3 weight%. The chiral dopant may be useful to remove reverse twist domains in the TN mode. There exists a wide variety of compounds suitable as members of component (ζ) all of which are readily available. Exemplary substances are

15   cholesterylnonanoate (CN), S-811, S-1011 and S-2011 and CB15 (Merck KGaA, Darmstadt, Germany). Although S-811 might be a preferred dopant, the specific choice of the dopants is not a critical issue.

The liquid crystal composition for use in the zenithal bistable nematic

20   devices of the invention may also contain one or more light stabilizers and/or additives like pleochromatic dyes known in the state of the art.

All the compounds used in the liquid crystal composition of the bistable liquid crystal devices are either commercially available or can be readily

25   prepared by methods known to those skilled in the art and as described in the standard text books of organic synthesis, for instance, in Houben-Weyl, *Methoden der Organischen Chemie*, Georg-Thieme-Verlag, Stuttgart. The liquid crystal composition will be prepared by applying standard protocols and techniques. In general, the desired amount of the minor component(s)

30   will be dissolved in the major component, usually under elevated temperature. Alternatively, solutions of components in organic solvents like acetone, chloroform or methanol, can be mixed and afterwards the

- 65 -

solvent(s) can be removed, e.g., by distillation. Likewise, manufacturing of the bistable devices according to the invention will follow standard techniques known to the artisan.

In the present description and the following examples the structures of the mesogenic compounds disclosed are described by using acronyms. Said acronyms can be transformed into chemical formulas according to Tables A and B. In these tables, radicals C_nH_{2n+1} and C_mH_{2m+1} are straight-chain alkyl radicals having n and m carbon atoms, respectively. Alkenyl radicals have the trans configuration. The codes according to Table B are self-evident. In Table A, only the acronym for the parent structure is given. In individual cases, the acronym for the parent structure is followed, usually separated by a hyphen, by a code for the substituents R^1, R^2, L^1 and L^2 as given below:

Code of R^1, R^2, L^1, L^2	R^1	R^2	L^1	L^2
n	C_nH_{2n+1}	CN	H	H
nm	C_nH_{2n+1}	C_mH_{2m+1}	H	H
nOm	C_nH_{2n+1}	OC_mH_{2m+1}	H	H
nF	C_nH_{2n+1}	F	H	H
nN.F	C_nH_{2n+1}	CN	F	H
nN.F.F	C_nH_{2n+1}	CN	F	F
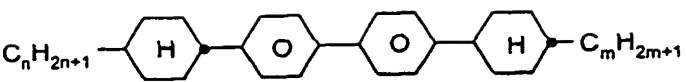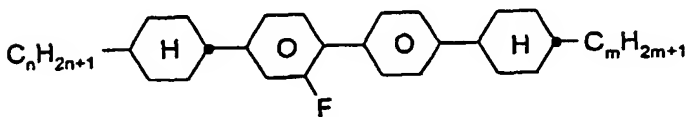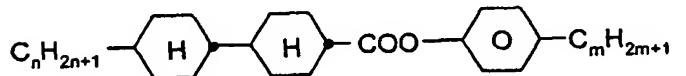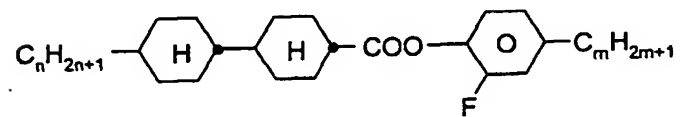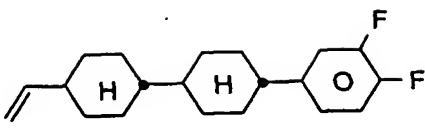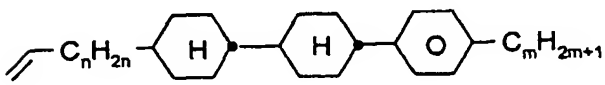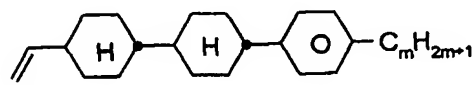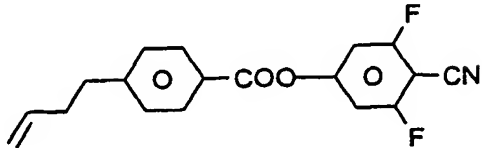
Table A:

5

PTP   **CPTP**

10

ME   **HP**

15

PCH   **CCPC**

20

PDX   **D**

25

PYP   **K6**

30

Table **B**:

5

C_nH_{2n+1} —⬡H— O — O —⬡H— C_mH_{2m+1}

CBC-nm

10

C_nH_{2n+1} —⬡H— O — O —⬡H— C_mH_{2m+1}
F

CBC-nmF

C_nH_{2n+1} —⬡H——⬡H— COO — O — C_mH_{2m+1}

CP-nm

15

C_nH_{2n+1} —⬡H——⬡H— COO — O — C_mH_{2m+1}
F

CP-nmF

20

C_nH_{2n+1} —⬡H——⬡H— ⧸

CC-n-V

⧸— ⬡H——⬡H— O —F, F

CCG-V-F

⧸— C_nH_{2n} —⬡H——⬡H— O — C_mH_{2m+1}

CCP-Vn-m

25

⧸— ⬡H——⬡H— O — C_mH_{2m+1}

CCP-V-m

⧸— O — COO — O —CN
F, F

PZU-V2-N

30

C_nH_{2n+1} —⬡O— —⬡O— —⬡O— PGU-n-F (with F substituents)

PGU-n-F

C_nH_{2n+1} —⬡H— —O,O dioxane— —⬡O—CN (with F substituents)

CDU-n-F

5

C_nH_{2n+1} —⬡H— —⬡H— —⬡O— —⬡O— (with F substituents)

CCGU-n-F

10

C_nH_{2n+1} —⬡H— —⬡H—CH_2O—⬡H—C_mH_{2m+1}

CCOC-n-m

15

C_nH_{2n+1}—⬡O——⬡O—C_mH_{2m} ═══ C_pH_{2p+1}

PP-n-mVp

C_nH_{2n+1} ═ —⬡H— ═ —⬡H— —⬡O—(O)-C_mH_{2m+1}

CVCP-nV-(O)m

C_nH_{2n+1} —⬡O— ≡ —⬡O— (O)C_mH_{2m+1}

PTP-n-(O)m

20

C_nH_{2n+1} —⬡H— —⬡O— ≡ —⬡O— (O)C_mH_{2m+1}

CPTP-n-(O)m

C_nH_{2n+1} —⬡O— —⬡O— ≡ —⬡O—C_mH_{2m+1} (with F substituents)

25

PPTUI-n-m

30

Table C:

Table C shows dopants optionally present in the liquid crystal compositions
for use in the zenithal bistable nematic devices of the invention (component
(ζ)).
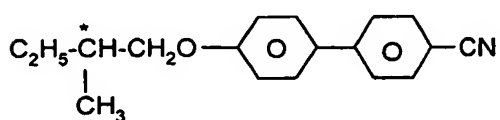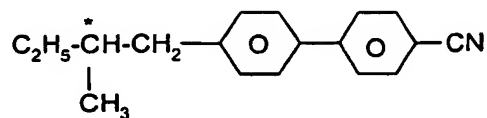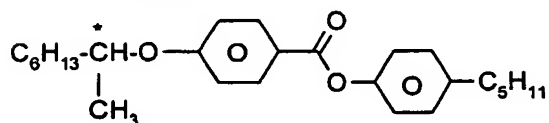
$C_2H_5\text{-}\overset{*}{C}H\text{-}CH_2O\text{-}$ ⬡-O-⬡-CN with CH₃ branch

C 15

$C_2H_5\text{-}\overset{*}{C}H\text{-}CH_2\text{-}$ ⬡-O-⬡-CN with CH₃ branch

CB 15

$C_6H_{13}\text{-}\overset{*}{C}H\text{-}O\text{-}$ ⬡-O-⬡-COO-⬡-O-⬡-C_5H_{11} with CH₃ branch

CM 21

$C_6H_{13}O\text{-}$ ⬡-O-⬡-COO-⬡-O-⬡-COO-$\overset{*}{C}H\text{-}C_6H_{13}$ with CH₃ branch

R/S-811

$C_3H_7\text{-}$ ⬡H-⬡H-⬡O-$CH_2\text{-}\overset{*}{C}H\text{-}C_2H_5$ with CH₃ branch

CM 44

$C_5H_{11}\text{-}$ ⬡-O-⬡-COO-$\overset{*}{C}H\text{-}$⬡-O with C_2H_5 branch

CM 45

$C_8H_{17}O\text{-}$ ⬡-O-⬡-COO-$\overset{*}{C}H\text{-}$⬡-O with C_2H_5 branch

CM 47

$C_5H_{11}\text{-}$ ⬡H-⬡O-COO-$\overset{*}{C}H\text{-}CH_2\text{-}OOC\text{-}$⬡-O-⬡H-$C_5H_{11}$ with phenyl branch

R/S-1011

R/S-3011

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CN

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R/S-2011

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R/S-4011

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R/S-5011

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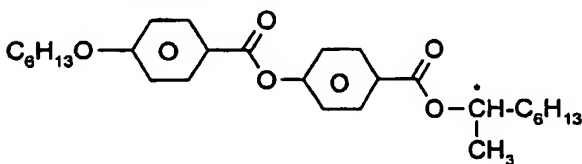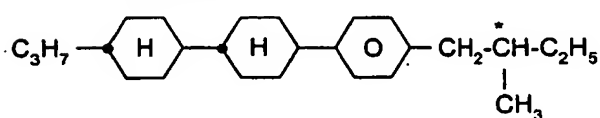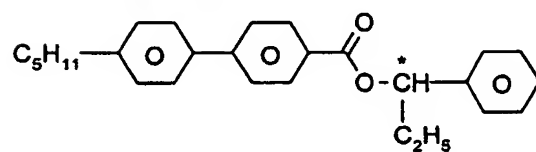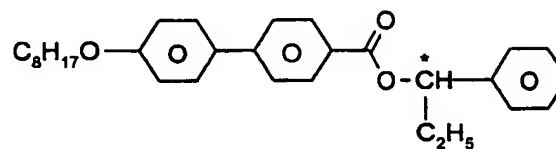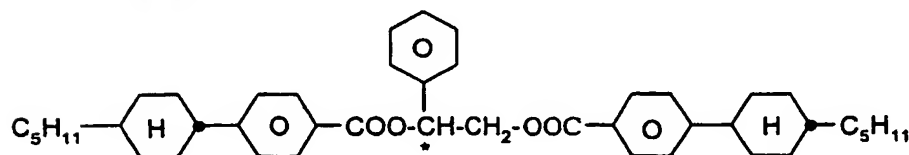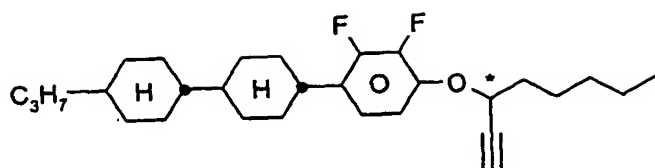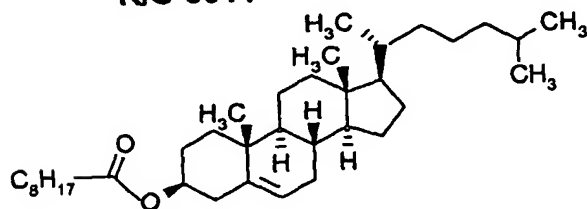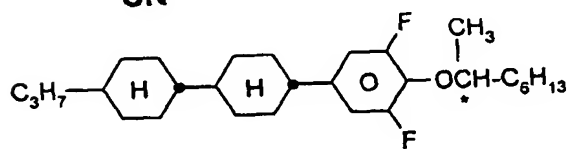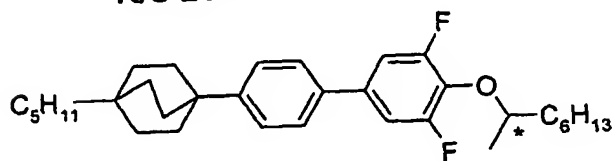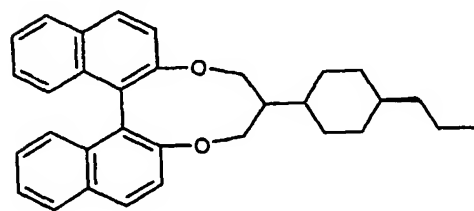
Table D:

Table D shows stabilizers optionally present in the liquid crystal compositions for use in the zenithal bistable nematic devices of the invention.

The structures are chemical stabilizer molecules with the following approximate textual descriptions:

HO—(O)—CH₂—(O)—OH (each ring bearing methyl and tert-butyl substituents)

HO—(O)—CH(with H above)—(O)—OH with isopropyl group (each ring bearing methyl and tert-butyl substituents)

HO—(O)—S—(O)—OH (each ring bearing methyl and tert-butyl substituents)

C_nH_{2n+1}—(H)—(O)—OH (ring bearing tert-butyl substituents)

C_nH_{2n+1}—(O)—OH (ring bearing tert-butyl substituents)

(O)—OH (ring bearing tert-butyl substituents)

$C_nH_{2n+1}O$—(O)—OH (ring bearing tert-butyl substituents)

HO—(O)—CH₂—(O)—OH (each ring bearing tert-butyl substituents)

O=C—O— attached to (O)—OH (ring bearing tert-butyl substituents)

$H_{37}C_{18}$-COO-C_2H_4—(O)—OH (ring bearing tert-butyl substituents)

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- 76 -

Percentages given herein are weight% and generally related to the total amount of a composition or mixture except stated otherwise. Temperatures are given in degree Celsius (°C) unless stated otherwise. T_{NI} means the clearing point at which a nematic medium becomes isotropic. Δn is the optical anisotropy (birefringence) (at 589 nm, 20 °C). $\Delta\varepsilon$ means the dielectric anisotropy (at 1 kHz, 20 °C). K_1 is the splay elastic constant, and K_3 is the bend elastic constant both given in pN. Electrooptical data has been determined in a VAN zenithal bistable nematic cell. Except stated otherwise the measurements have been performed at 20 °C. V_{opt} is the corrected operating voltage (in V) derived from the corrected switching field $E_{LC@100\mu s}$ (at 25 °C; in zenithal bistable test cells with the actual cell gap d of about 2.8 to about 5 μm; 100 μs pulse) by $V_{opt} = E_{LC@100\mu s} \cdot d_{opt}$ (with d_{opt} (in μm) being $\lambda\sqrt{3}/(2\Delta n)$; λ = 555 nm). ΔV_{opt} is the corrected operating window at a 400 μs pulse for B-W-switching and reverse switching (in V); it is calculated from the experimental switching field window $\Delta E_{LC@400\mu s}$ (at 25 °C; 400 μs pulse) multiplied with d_{opt} defined as given above. Optical response time τ_{opt} (in ms) is calculated from $\tau_{opt} = \tau \cdot d^2_{opt}/d^2$ with τ being the experimental response time, d_{opt} being as defined above and d being the experimental cell gap.

The following Examples should further illustrate the present invention as described above and in the claims but not meant to restrict its scope.

Examples

Test samples were prepared by weighing out the appropriate weight amounts (percentage weight/weight) of the individual components. The
5   sample was then homogenised by heating into the isotropic phase and thoroughly mixing. The mixture was then stirred with a given concentration of alumina and then filtered (0.2μm) to just leave the liquid crystal mixture. The nematic to isotropic transition temperature (or clearing point, T_{NI}), dielectric anisotropy ($\Delta\varepsilon$), birefringence (Δn), splay and bend elastic
10   constants (K_1 and K_3), and rotational viscosities (γ_1) were determined as described in the Merck brochure "Physical Properties of Liquid Crystals – Description of the measurement methods", ed. W. Becker (1998). Values for single compounds are extrapolated from those determined using a known concentration (usually 10 weight% of the single compound) in a
15   standard host mixture for which the initial mixture values are also known. The electrooptical performance of each mixture in a zentihal bistable nematic device was measured using a simple experimental set-up and the VAN type test cells. This required a transmissive mode micrscope with a mounted photo-detector connected to an oscilloscope. This allowed the
20   transmission through crossed polarisers to be monitored. The test cell was mounted on a heating stage under the microscope to permit measurements at 25°C. Bipolar electrical pulses (of varying duration and voltage) were used to ensure that there was no net d.c. voltage applied to the cell. The trailing edge (and so polarity) of each pulse therefore determined the final
25   switched state (depending on the duration and voltage). Two signal generators were necessary to ensure that the correct initial state is first selected, with the first signal triggering the second (with an appropriate phase difference). Both signals were amplified by passing the output of the signal generators through an amplifier before being connected to the test
30   cell. For the B-W transition, the voltages required for 10 and 90% transmission changes and reverse 90 and 10% transmission changes were

measured for various pulse durations. For the W-B transition, the voltages required for 90 and 10% transmission changes only were measured for various pulse durations. These levels were set on the oscilloscope once the 0 and 100% transmission levels were known (i.e. black and white), and

5   they could also be used to determine the optical response time of the transition (for 10 to 90% transmission changes).

VAN type test cells were used with cell gaps typically 3-5μm, in transmissive mode and with crossed polarisers. Due to the varying cell

10   thicknesses and different mixture Δn values, the retardation was not optimised but this is not crucial as it only decreases the contrast.

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Example 1

Compound	Amount (wt%)	T_{NI} (°C)	95.0
ME2N.F	10	$\Delta\varepsilon$	46.5
ME3N.F	10	Δn	0.1682
ME4N.F	10	K_1 (pN)	9.2
ME5N.F	10	K_3 (pN)	19.1
PZU-V2-N	10	V_{opt} (V)	13.8
CPTP-301	5	ΔV_{opt} (V)	3.9
CPTP-302	5	τ_{opt} (ms)	28
CPTP-303	5		
CCG-V-F	10		
CCP-V-1	10		
CCP-V2-1	5		
CVCP-V-O1	5		
CVCP-1V-O1	5		
Total	100		

Example 2

Compound	Amount (wt%)	T_{NI} (°C)	91.9
ME2N.F	12	$\Delta\varepsilon$	45.3
ME3N.F	12	Δn	0.1714
ME4N.F	12	K_1 (pN)	9.2
ME5N.F	12	K_3 (pN)	19.0
HP-3N.F	5	V_{opt} (V)	19.7
HP-4N.F	5	ΔV_{opt} (V)	9.0
HP-5N.F	5	τ_{opt} (ms)	25
CC-5-V	12		
CCP-V-1	10		
CPTP-301	5		
CPTP-302	5		
CPTP-303	5		
Total	100		

Example 3

Compound	Amount (wt%)	T_{NI} (°C)	95.8
ME2N.F	10	$\Delta\varepsilon$	48.0
ME3N.F	10	Δn	0.1816
ME4N.F	10	K_1 (pN)	10.9
ME5N.F	10	K_3 (pN)	18.8
PZU-V2-N	10	V_{opt} (V)	16.0
CPTP-301	5	ΔV_{opt} (V)	8.6
CPTP-302	5	τ_{opt} (ms)	8
CPTP-303	5	$\gamma 1$ (mPa.s)	341
CCP-V-1	15		
CCP-V2-1	15		
PPTUI-3-2	5		
Total	100		

Example 4

Compound	Amount (wt%)		
ME2N.F	9	T_{NI} (°C)	90.9
ME3N.F	9	$\Delta\varepsilon$	45.2
ME4N.F	9	Δn	0.2471
ME5N.F	9	K_1 (pN)	11.6
PZU-V2-N	9	K_3 (pN)	14.6
PPTUI-3-2	20	V_{opt} (V)	26.4
PPTUI-3-4	25	τ_{opt} (ms)	1
CCP-V-1	5	$\gamma 1$ (mPa.s)	361
CCP-V2-1	5		
Total	100		

Example 5

Compound	Amount (wt%)		
ME2N.F	10	T_{NI} (°C)	97.1
ME3N.F	10	$\Delta\varepsilon$	47.8
ME4N.F	10	Δn	0.1569
ME5N.F	10	K_1 (pN)	11.3
PZU-V2-N	10	K_3 (pN)	19.4
CCPC-33	5	V_{opt} (V)	8.7
CCPC-34	5	τ_{opt} (ms)	11
CCPC-35	5	$\gamma 1$ (mPa.s)	407
CCP-V-1	15		
CCP-V2-1	15		
PPTUI-3-2	5		
Total	100		

Example 6

Compound	Amount (wt%)		
		T_{NI} (°C)	96.7
ME2N.F	12	$\Delta\varepsilon$	48.3
ME3N.F	12	Δn	0.1674
ME4N.F	12	K_1 (pN)	10.0
ME5N.F	12	K_3 (pN)	20.7
HP-3N.F	5	V_{opt} (V)	12.8
HP-4N.F	5	ΔV_{opt} (V)	28.6
HP-5N.F	5	τ_{opt} (ms)	17
CCP-V-1	16	$\gamma 1$ (mPa.s)	433
CCP-V2-1	16		
PPTUI-3-2	5		
Total	100		

Example 7

Compound	Amount (wt%)		
		T_{NI} (°C)	90.0
ME2N.F	10	$\Delta\varepsilon$	57.3
ME3N.F	10	Δn	0.1816
ME4N.F	10	K_1 (pN)	8.4
ME5N.F	10	K_3 (pN)	16.1
PZU-V2-N	10	V_{opt} (V)	11.7
HP-3N.F	5	ΔV_{opt} (V)	8.5
HP-4N.F	5	τ_{opt} (ms)	18
HP-5N.F	5		
CC-5-V	9		
CCP-V-1	4		
CCP-V2-1	4		
CPTP-301	5		
CPTP-302	5		
CPTP-303	5		
PPTUI-3-2	3		
Total	100		

Example 8

Compound	Amount (wt%)	T_{NI} (°C)	93.5
ME2N.F	10	$\Delta\varepsilon$	48.4
ME3N.F	10	Δn	0.1528
ME4N.F	10	K_1 (pN)	10.5
ME5N.F	10	K_3 (pN)	20.1
PZU-V2-N	10	V_{opt} (V)	8.7
CC-5-V	6	ΔV_{opt} (V)	7.3
CCP-V-1	10	τ_{opt} (ms)	20
CCP-V2-1	10		
CBC-33F	4		
CBC-53F	4		
CBC-55F	4		
CBC-33	4		
CBC-53	4		
CBC-55	4		
Total	100		

Example 9

Compound	Amount (wt%)	T_{NI} (°C)	93.4
ME2N.F	10	$\Delta\varepsilon$	72.0
ME3N.F	10	Δn	0.1842
ME4N.F	10	K_1 (pN)	7.1
ME5N.F	10	K_3 (pN)	16.7
PZU-V2-N	15	V_{opt} (V)	10.6
HP-3N.F	5	ΔV_{opt} (V)	8.5
HP-4N.F	5	τ_{opt} (ms)	27
HP-5N.F	5		
CCP-V-1	8		
CCP-V2-1	7		
CPTP-301	5		
CPTP-302	5		
CPTP-303	5		
Total	100		

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Example 10

Compound	Amount (wt%)	T_{NI} (°C)	90.7
ME2N.F	10	$\Delta\varepsilon$	45.9
ME3N.F	10	Δn	0.1569
ME4N.F	10	K_1 (pN)	9.9
ME5N.F	10	K_3 (pN)	18.1
PZU-V2-N	10	V_{opt} (V)	11.4
CCP-V-1	15	ΔV_{opt} (V)	11.2
CCP-V2-1	15	τ_{opt} (ms)	17
PPTUI-3-2	5	$\gamma 1$ (mPa.s)	290
CVCP-V-1	5		
CVCP-V-O1	5		
CVCP-1V-O1	5		
Total	100		

Example 11

Compound	Amount (wt%)	T_{NI} (°C)	95.9
ME2N.F	10	$\Delta\varepsilon$	51.2
ME3N.F	10	Δn	0.1639
ME4N.F	10	K_1 (pN)	10.8
ME5N.F	10	K_3 (pN)	18.2
PZU-V2-N	10	V_{opt} (V)	10.7
CCP-V-1	15	τ_{opt} (ms)	17
CCP-V2-1	15		
PPTUI-3-2	5		
CBC-33F	5		
CBC-53F	5		
CBC-55F	5		
Total	100		

Example 12

Compound	Amount (wt%)	T_{NI} (°C)	91.3
ME2N.F	10	$\Delta\varepsilon$	55.8
ME3N.F	10	Δn	0.1801
ME4N.F	10	K_1 (pN)	9.7
ME5N.F	10	K_3 (pN)	15.3
PZU-V2-N	14	V_{opt} (V)	17.4
CCP-V-1	8	ΔV_{opt} (V)	9.5
CCP-V2-1	8	τ_{opt} (ms)	33
PPTUI-3-2	5		
CPTP-301	5		
CPTP-302	5		
CPTP-303	5		
CC-5-V	4		
CCPC-33	2		
CCPC-34	2		
CCPC-35	2		
Total	100		

Example 13

Compound	Amount (wt%)	T_{NI} (°C)	96.2
ME2N.F	12	$\Delta\varepsilon$	47.3
ME3N.F	12	Δn	0.1737
ME4N.F	12	K_1 (pN)	9.8
ME5N.F	12	K_3 (pN)	20.4
HP-3N.F	5	V_{opt} (V)	17.0
HP-4N.F	5	τ_{opt} (ms)	18
HP-5N.F	5		
CCP-V-1	10		
CCP-V2-1	10		
CBC-33F	3		
CBC-53F	3		
CBC-55F	3		
PTP-201	4		
PTP-301	4		
Total	100		

Example 14

Compound	Amount (wt%)	T_{NI} (°C)	95.3
PZU-V2-N	10	$\Delta\varepsilon$	49.2
ME2N.F	10	Δn	0.1420
ME3N.F	10	K_1 (pN)	9.7
ME4N.F	10	K_3 (pN)	17.1
ME5N.F	10	V_{opt} (V)	8.6
CCPC-33	4	τ_{opt} (ms)	30
CCPC-34	4		
CCPC-35	4		
CCP-V-1	8		
CCP-V2-1	8		
CC-5-V	10		
CBC-33F	4		
CBC-35F	4		
CBC-55F	4		
Total	100		

Example 15

Compound	Amount (wt%)	T_{NI} (°C)	97.3
ME2N.F	10	$\Delta\varepsilon$	34.3
ME3N.F	10	Δn	0.1393
ME4N.F	10	K_1 (pN)	10.8
ME5N.F	10	K_3 (pN)	17.9
ME7N.F	10	V_{opt} (V)	14.4
CCPC-33	4	τ_{opt} (ms)	24
CCPC-34	4		
CCPC-35	4		
CCP-V-1	6		
CCP-V2-1	6		
CC-5-V	14		
CBC-33F	4		
CBC-35F	4		
CBC-55F	4		
Total	100		

Example 16

Compound	Amount (wt%)	T_{NI} (°C)	85.6
PZU-V2-N	20	$\Delta\varepsilon$	44.2
ME3N.F.F	10	Δn	0.1106
CDU-2-F	10	K_1 (pN)	9.1
CDU-3-F	10	K_3 (pN)	17.9
CDU-5-F	10	V_{opt} (V)	5.9
CC-5-V	5	ΔV_{opt} (V)	33.5
CCP-V-1	10	τ_{opt} (ms)	34
CCP-V2-1	10		
CCPC-33	5		
CCPC-34	5		
CCPC-35	5		
Total	100		

Example 17

Compound	Amount (wt%)	T_{NI} (°C)	95.5
PZU-V2-N	20	$\Delta\varepsilon$	54.3
ME3N.F.F	10	Δn	0.1741
PGU-2-F	10	K_1 (pN)	9.3
PGU-3-F	10	K_3 (pN)	17.0
PGU-5-F	10	V_{opt} (V)	5.6
CCP-V-1	15	ΔV_{opt} (V)	21.1
CCP-V2-1	10	τ_{opt} (ms)	17
CCPC-33	5		
CCPC-34	5		
CCPC-35	5		
Total	100		

Example 18

Compound	Amount (wt%)	T_{NI} (°C)	92.2
PZU-V2-N	20	$\Delta\varepsilon$	47.2
ME2N.F	7	Δn	0.1341
ME3N.F	6	K_1 (pN)	10.3
ME4N.F	4	K_3 (pN)	18.3
ME5N.F	3	V_{opt} (V)	7.8
CDU-2-F	5	τ_{opt} (ms)	21
CDU-3-F	5		
CDU-5-F	5		
PP-1-2V1	6		
CCP-V-1	12		
CCP-V2-1	12		
CCPC-33	5		
CCPC-34	5		
CCPC-35	5		
Total	100		

Example 19

Compound	Amount (wt%)	T_{NI} (°C)	106.2
PZU-V2-N	19	$\Delta\varepsilon$	57.4
ME2N.F	5	Δn	0.1534
ME3N.F	5	K_1 (pN)	7.8
ME4N.F	5	K_3 (pN)	12.7
ME5N.F	5	V_{opt} (V)	6.5
PGU-2-F	5	ΔV_{opt} (V)	31.1
PGU-3-F	5	τ_{opt} (ms)	29
PGU-5-F	5		
CCGU-3-F	5		
CCP-V-1	13		
CCP-V2-1	13		
CCPC-33	5		
CCPC-34	5		
CCPC-35	5		
Total	100		

Example 20

Compound	Amount (wt%)	T_{NI} (°C)	91.7
PZU-V2-N	15	$\Delta\varepsilon$	39.0
ME2N.F	5	Δn	0.1195
ME3N.F	5	K_1 (pN)	10.3
ME4N.F	5	K_3 (pN)	17.3
ME5N.F	5	V_{opt} (V)	5.4
CDU-2-F	5	ΔV_{opt} (V)	19.6
CDU-3-F	5	τ_{opt} (ms)	30
CDU-5-F	5		
CCGU-3-F	5		
CCP-V-1	15		
CCP-V2-1	15		
CCOC-3-3	5		
CCOC-3-5	5		
CCOC-4-3	5		
Total	100		

Example 21

Compound	Amount (wt%)	T_{NI} (°C)	102.5
PZU-V2-N	20	$\Delta\varepsilon$	47.8
ME2N.F	5	Δn	0.1462
ME3N.F	5	K_1 (pN)	12.1
ME4N.F	5	K_3 (pN)	20.2
ME5N.F	5	V_{opt} (V)	5.9
CCGU-3-F	5	ΔV_{opt} (V)	30.6
PP-1-2V1	10	τ_{opt} (ms)	16
CCP-V-1	15		
CCP-V2-1	15		
CCPC-33	5		
CCPC-34	5		
CCPC-35	5		
Total	100		

Example 22

Compound	Amount (wt%)		
		T_{NI} (°C)	84.7
PZU-V2-N	25	$\Delta\varepsilon$	40.5
PCH-3N.F.F	5	Δn	0.1532
PGU-2-F	10	K_1 (pN)	10.0
PGU-3-F	10	K_3 (pN)	16.8
PGU-5-F	10	V_{opt} (V)	6.1
CCP-V-1	15	ΔV_{opt} (V)	7.8
CCP-V2-1	10	τ_{opt} (ms)	34
CCPC-33	5		
CCPC-34	5		
CCPC-35	5		
Total	100		

Comparative Example

MLC-6204 (Merck KGaA, Darmstadt) was tested under similar conditions as the Examples according to the invention:

T_{NI} (°C)	62.4
$\Delta\varepsilon$	35.2
Δn	0.1484
K_1 (pN)	7.5
K_3 (pN)	14.8
V_{opt} (V)	11.8
ΔV_{opt} (V)	7.3
τ_{opt} (ms)	41
$\gamma 1$ (mPa.s)	358